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Sonometer.
(One String Electric Guitar.

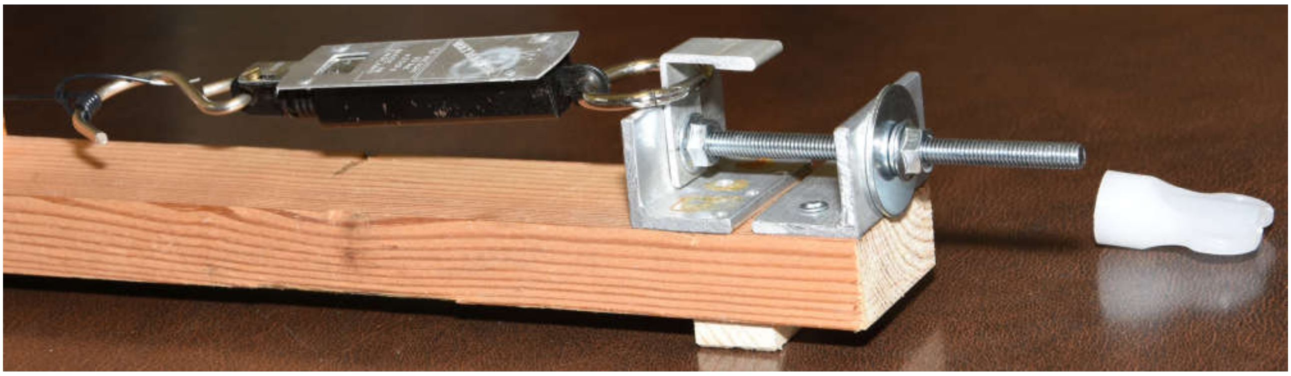
This is a description of a one stringed electric guitar, built from mostly 'scrap' materials, but which can be used to investigate sounds produced by a vibrating string.
None of the components are critical and so the design can be adapted to fit the materials available.

The main body was made from a 1m length of salvaged 44mm x 21mm planed wood.
To make the device more portable, the wood was cut into two 500mm lengths and joined with a hinge. The hinge was secured across the junction of the two pieces of wood.

Since the hinge is on the underside of the body, four small pieces of wood were fixed to the body to act as feet and enable the body to sit flat on the table. Two of the feet are visible in the picture above, the other two are fitted at the ends.

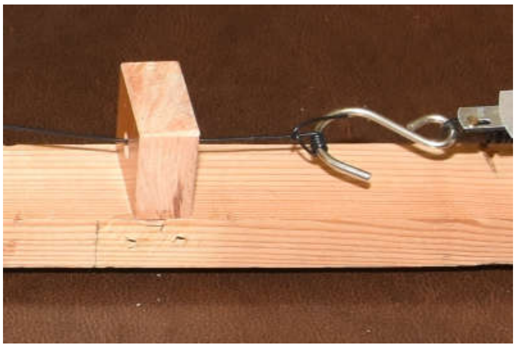
A 25mm long screw was put into the of the body which was used to secure one end of the wire.

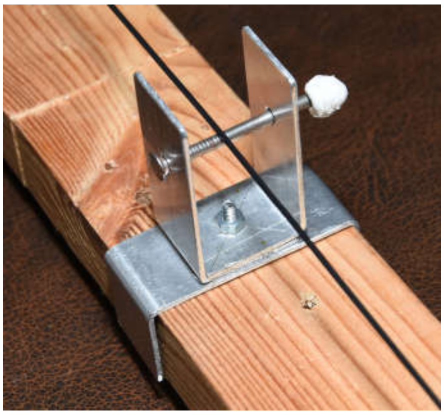
A 'bridge' was also fixed near to this end to lift the wire clear of the body by about 30mm.



The picture above shows the system used to adjust the tension in the wire, a 100N spring balance indicating the tension.
Two brackets were made from 25mm angle aluminium, though these could be replaced with blocks of wood. An 8mm diameter hole was drilled through the centre of one of the sides of each bracket.
One of these brackets was fixed to the end of the body with two screws.
A smaller aluminium bracket was fixed to the other bracket using a 100mm M8 coach bolt and nut.
This formed a hook to attach the spring balance. The whole of this bracket is free to move.
The M8 bolt was then passed through the 8mm hole in the fixed bracket and fitted with a large M8 washer, a small M8 washer and an M8 nut. This nut could be replaced with an M8 wing nut, as it would make adjusting the tension in the wire easier.
(The white object in the picture is an M8 plastic spanner originally supplied with a replacement toilet seat!)

A piece of wood, drilled with a 6mm hole is secured to the body. The 6mm hole was 15mm above the body and was used to keep the wire near to the body prior to it passing over the movable bridge.





The moveable bridge was made from two bent pieces of aluminium, glued and bolted together.
Two 3mm holes were drilled into the top bracket at a height of ~30mm above the base. A nail was pushed through the holes to form a roller for the wire.
The white blob on the end of the nail is 'White Tack' to help prevent the nail from falling out.
Wood could be used to make the moveable bridge if aluminium is not available.

The distance between the moveable bridge and the end bridge defines the length of wire which vibrates.

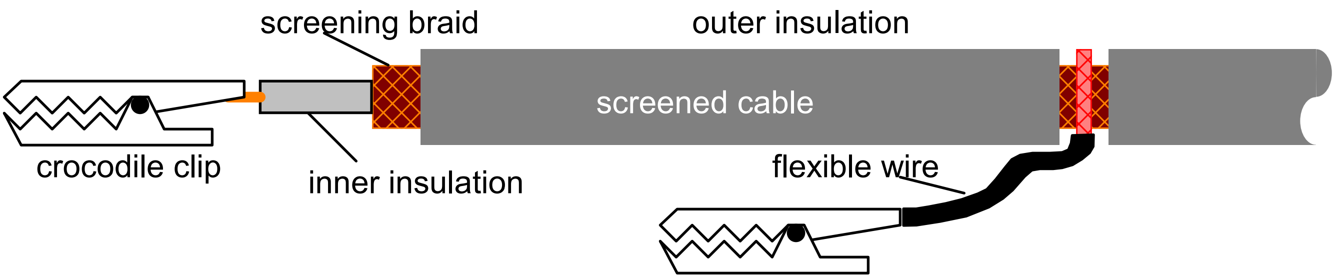
The wire used is not critical and standard solid core connecting wire was used in this version.
The insulation was left on the wire which had the effect of increasing the mass per unit length of the wire and so lowered the frequency of vibration. The insulation was removed from the very ends of the wire to allow connection to an amplifier.
Metal guitar strings could be used with the advantage that they could produce a greater range of frequencies.

The sound produced by the wire when plucked is very quiet, since the body does not vibrate with the wire (as in an acoustic string instrument).

When a wire moves in a magnetic field a voltage is produced. If the vibrating wire were placed in a magnetic field an oscillating voltage would be produced across the ends of the wire which could then be amplified electronically.

The picture opposite shows the magnets used in the original. A bent piece of aluminium forms the bottom part and this is glued and bolted to a bent piece of steel (from an old computer case).
The magnets were 20mm diameter and made from Neodymium and were very strong!
(**N.B.** Care should be taken to ensure that pinch injuries do not occur from the magnets and also that no iron or steel dust gets onto the magnets as it is impossible to remove.)
The magnets are positioned at the same height as the wire and so that there is a N - S field across the wire.
The magnet arrangement should be moveable so that it can be positioned near to the centre of the wire. This is where there will be the maximum movement of the wire and so the maximum voltage generated.

The voltage produced across the ends of the wire is only of the order of a few mV. This is less than the output from an electric guitar (several hundred mV) but is of the same order as that from a magnetic microphone.
A piece of screened cable was used to connect the wire to the microphone input of an amplifier to reduce 'mains hum'.



The screened cable extended the full length of the body and a crocodile clip attached to the inner conductor. The end of the screened cable is wrapped with 'gaffer' type tape to cover the screening braid and provide protection to the inner conductor. This crocodile clip was used to make a connection to the wire where it is secured to the body.
A connection for the other end of the wire is made to the screening braid of the cable by carefully removing a small section of the outer insulation and wrapping a short length of flexible wire around the exposed screening braid. Ideally this connection should be soldered, but care must be taken not to melt the inner insulation of the screened cable. The connection was protected with gaffer tape and a crocodile clip was fixed to the end of the wire.
The other end of the screened cable should be fitted with a suitable plug to match the amplifier input.

Investigations

Qualitative

1). Observe how the length of the wire between the two bridges affects the pitch of the sound.

2) Observe how the tension of the wire affects the pitch of the sound.

3). Observe how thicker/thinner wire affects the pitch of the sound.

4). Observe what happens to the pitch of the sound if the wire near to the spring balance is pressed towards the body. This is known as 'bending' the pitch on a guitar.

5). Observe how moving the magnets nearer to the end of the vibrating wire affects the tone of the sound. This is the reason why some electric guitars have one pickup near to the end of the strings and another one nearer to the middle of the strings.

6). For this experiment the amplifier loudspeaker is placed near to the vibrating wire and the volume control turned up loud. When the wire is sounded, the sound should continue for much longer than when the speaker is not close to the wire. This is known as '**Sustain**' and is when the sound from the speaker interacts with the wire and keeps it vibrating.
This effect is more easily achieved with some frequencies more than others and can be investigated. This will depend on the amplifier and speaker natural frequencies of vibration. For some frequencies, the frequency of the sound that is sustained will be a multiple (harmonic) of the original sound.

Investigations

Quantitative

If the frequency measuring device is available then the observations above can be backed up with measurements and mathematical relationships determined. Some digital multimeters have a frequency measuring function, although they are often not very sensitive and will need to be connected to the speaker output of the amplifier.
The free computer programme, 'Audacity' can also be used to measure frequency by recording the sounds and then using Audacity to analyze the sounds, using the 'Plot Spectrum' function.
Audacity will also enable you to 'see' what the waveform looks like for the sound made by the vibrating wire.

1). Record the length of the wire between the two bridges and the frequency of the sound produced, while the tension and type of wire are kept constant.
10 separate measurements should be sufficient.
Either plot a graph of the results or enter the measurements into a spreadsheet program (e.g. Excel) and get the computer to plot the graph.
The graph that is produced should be a curve, which is difficult to interpret mathematically.
Plotting a new graph of frequency against (1/length of the vibrating wire), should produce a straight line graph passing through the origin, indicating that

frequency ∝ 1/length

2) Record the tension of the wire and the frequency of the sound produced, while the length and type of wire are kept constant.
10 separate measurements should be sufficient, be careful not to apply so much tension that the wire either breaks or becomes permanently stretched.
Either plot a graph of the results or enter the measurements into a spreadsheet program (e.g. Excel) and get the computer to plot the graph.
The graph that is produced should be a curve, which is difficult to interpret mathematically.
Plotting a new graph of frequency against (√ of the tension of the wire), should produce a straight line graph passing through the origin, indicating that

frequency ∝ √tension

3) Using several different wires, measure the frequency of the sound produced for the same length and tension for each wire.
Measure the mass of each wire and divide by its length to find the mass per unit length.
If five different wires are available then plot a graph of frequency against mass per unit length
The graph that is produced should be a curve, which is difficult to interpret mathematically.
Plotting a new graph of frequency against (√1/mass per unit length of the wire), should produce a straight line graph passing through the origin, indicating that

frequency ∝ √1/mass per unit length

4). Combining all of these together gives a formula for the frequency of a vibrating wire/string.

$$f = \frac{1}{2l}\sqrt{\frac{T}{M_o}}$$

where f = frequency (Hz)
l = length of vibrating string (m)
T = tension (N)
M_o = mass per unit length of the string (kg m^{-1})

The ½ comes from the fact that the sound produced is for the string being a half wavelength long.

5). The change in tone produced by moving the position of the magnets can be investigated quantitatively by recording the sounds with Audacity and then using the 'Plot Spectrum' function.
With the magnets near to the middle of the vibrating string, one main frequency should be clearly visible. This is the fundamental frequency.
With the magnets near to the end of the vibrating string, several other higher frequencies should be present, which are multiples of the fundamental frequency.
The tone of the note will be harsher than when the magnets are near to the centre of the wire.