Feedback and the Theremin: using micro-controllers in the classroom

Leon Theremin 1896 - 1993

Leon or Lev Theremin was born in the Russian Empire. He led an extraordinary life as a spy and inventor and this in itself would be a great subject for motivating students. His "listening" device was concealed in a wooden carving of the Great Seal of the United States and presented to the US ambassador by Soviet schoolchildren in 1945. It was only discovered accidentally in 1952. He also invented "interlacing", a technique where each video frame misses alternate lines and these lines are filled in during the next frame. All students benefit from watching enhanced motion on television in this way, and they have Leon Theremin to thank for it.

The Theremin

Leon Theremin was experimenting with high frequency electric circuits. At the time radio waves had just been discovered by Heinrich Hertz (1887) and Leon was transmitting radio waves from one device to another. The antennae were simply one terminal of his high frequency capacitors. He decided to make the signal audible and used the simple method of mixing two signals close together in frequency and getting a beat frequency which is in the audio range. This is called heterodyning and can be demonstrated by sounding two tuning forks close together in frequency and listening for the beats. Leon discovered accidentally that he could change the frequency by moving his hand closer to or away from the antenna which was in fact one of the capacitor plates in his high frequency circuit. He was changing the capacitance and this was fed back into the circuit as a change in frequency so that he could control the pitch by simply moving his hand in the air! He had created the first electronic musical instrument and although he called it the Etherphone, it became known as the Theremin.

Making

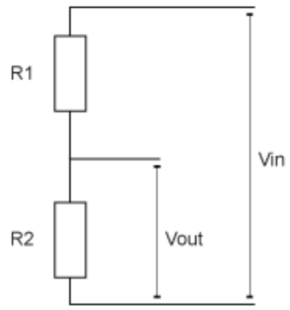
Across Europe there is a lot of chatter about the "maker" culture. This culture is technology-based and focuses on the creation of new devices and the modification of existing ones. It embodies all the STEM subjects and twenty years ago would have been an aspect of electronics. Creating devices would have needed a knowledge of logic gates and how to use various chips to complete a task.

Europe also faces a STEM crisis, not enough young people coming through compulsory education to study the STEM subjects. The world to-day is a digital world and young people deserve to have some knowledge of the way this digital environment is constructed. Bringing coding into the curriculum to stimulate an interest in the STEM subjects may be a good way to capture young people's imaginations.

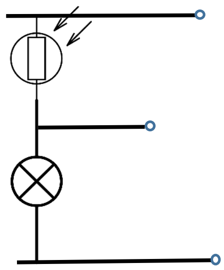
Today we have a range of micro-controllers which do all the micro-electronics for us, all we have to do is programme them. This is where coding comes in, and what better way to motivate young people than to make music. But first a little bit about feedback and control.

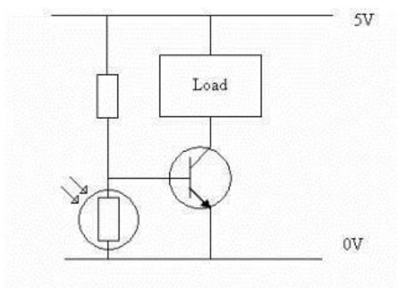
Feedback and Control: the night light

At their heart all micro-controllers are feedback and control devices. Sensors collect data from the environment and feed it back to actuators such as motors, switches, speakers and relays. One group of teachers known as T[3] Europe is exploring the use of the TI-Innovator for motivating students through coding and "making". There are many other such devices such as the Arduino and the Raspberry-Pi. Although they all have feedback and control in common they use different programming languages. The TI-Innovator uses a form of BASIC making it particularly easy to program, and this will be the language used in this article. Micro-controllers generally accept input via bespoke terminals or a breadboard. Output is via bespoke terminals or the same breadboard. Sensors provide voltages (potential differences) at the inputs and devices such as lamps, motors and speakers can be connected to the outputs.

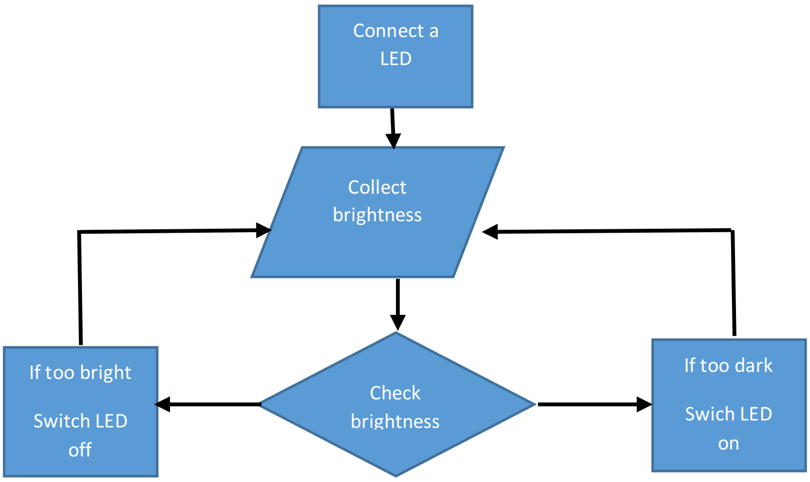


At some point in their studies most students will investigate the potential divider. Two resistors in series, R_1 and R_2 simply divide the potential difference in the ratio of their resistances, fig 1Variable resistance devices such as thermistors or light dependent resistors (LDRs) can be used as the resistors and so the ratio of the potential differences will change. In this way a light dependent resistor (in the place of R_1) can be made to switch a lamp (in the place of R_2) on and off, fig 2. This is very simple feedback and control. Unfortunately light dependent resistors increase their resistance in the dark so that the potential difference across the lamp will decrease, so switching it off in the dark and on in the light! The problem is overcome by connecting the gate of a transistor to the mid-point of the two resistors and using the changing potential at this point to switch a lamp on and off, fig 3. The TI-Innovator has a built in light and light sensor so it is only necessary to connect it to a handheld device such as the TI-Nspire and enter the programme.





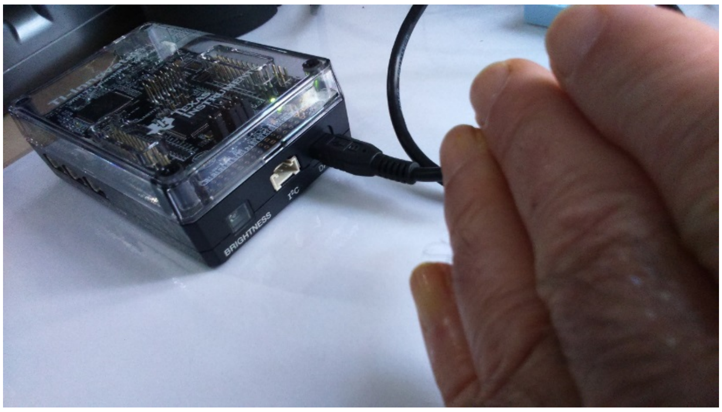
```
Prgm
:Local b
:Send "CONNECT LED 1 OUT 1 "
:Lbl a
  :Send "READ BRIGHTNESS "
  :Get b
  :If b<2 Then
  :Send "SET LED 1 ON "
  :Else
  :Send "SET LED 1  OFF "
  :EndIf
:Goto a
:EndPrgm
```



In this way the light is switched on when the brightness b drops below a certain point. You can see in the code above that the light is switched on when the brightness drops below 2. In this example the logical if/else statement is used as well as a set of Send commands which consist of strings which are read and interpreted by the micro-controller. Being able to write an algorithm, fig 4, to solve a problem is now considered an important of a young person's education and sending code to a microcontroller is a useful way to achieve this.

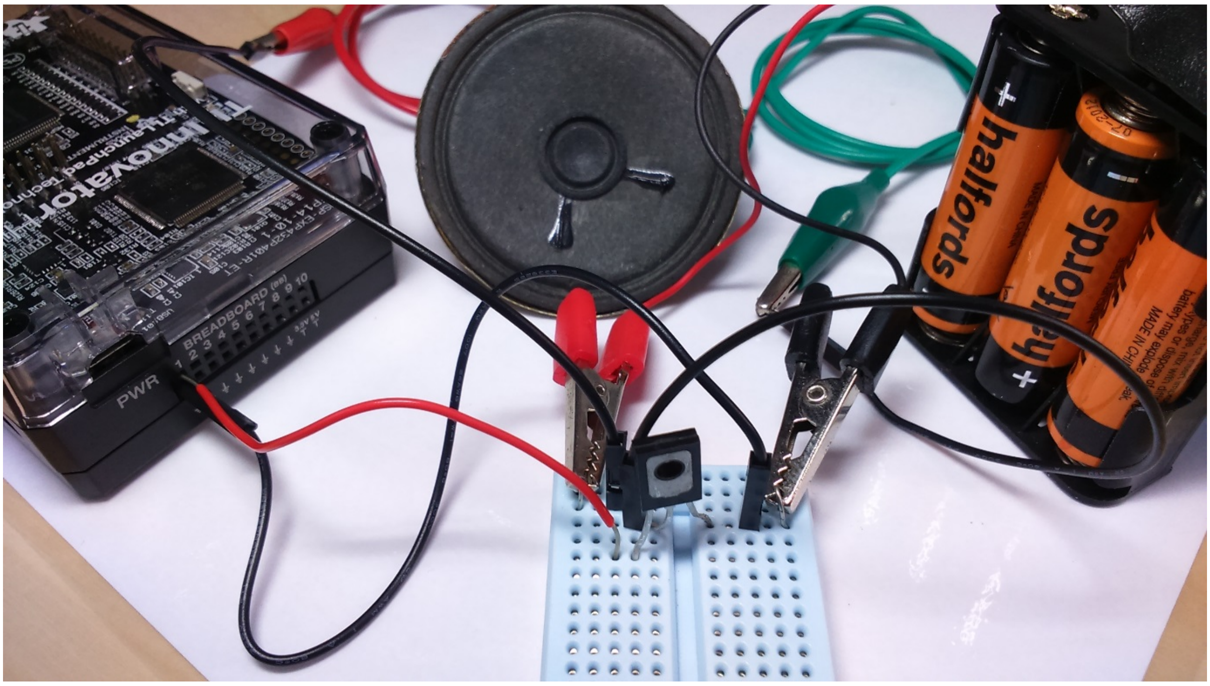
Turning the nightlight into a Theremin

It is now easy to see that the output to a loudspeaker could be controlled by changing the brightness from a lamp. There is a built in speaker on the TI-Innovator which means the only requirement is a source of light, the window! This is now a simple electronic instrument which works by the same principle as a Theremin.



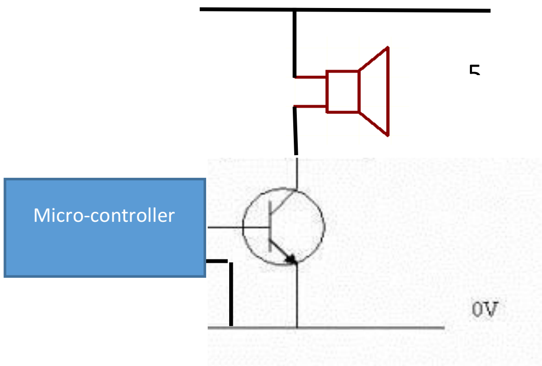
```
Prgm
:Local b
:For i,1,100
  :Send "READ BRIGHTNESS "
  :Get b
  :Send "SET SOUND eval(b*100)  TIME 0.2"
  :Wait 0.2
:EndFor
:EndPrgm
```

In this case a programming loop is covered 100 times (starting For and ending at EndFor) and so 100 separate tones can be made each lasting 0.2 seconds. The frequency of each burst is the brightness number times 100 to put the pitch into the audible range. The string of expressions in the SEND or SET command is interpreted by the micro-controller as a set of commands and students will have to know how their particular micro-controller handles these strings.



The volume from the built in speaker is limited and students will want to improve on this. Referring back to fig 3, a small loudspeaker can be used for the load. The red lead in image 4 goes to the gate of the transistor. The transistor (BD 237 in image 4) then controls the current from an external power supply to the speaker, but it is the micro-controller which switches the transistor on and off. In this way much greater volumes of sound can be produced and students will also learn that any device can be used as the load in this way.

```
Prgm
:Local b
:Send "CONNECT SPEAKER 1  TO BB 1 "
:For i,1,100
  :Send "READ BRIGHTNESS "
  :Get b
  :Send "SET SPEAKER 1  TO eval(b*100)  TIME 0.2"
  :Wait 0.2
:EndFor
:EndPrgm
```



The external speaker has been connected to a power supply through a transistor. The gate (or base) of the transistor has been connected to a breadboard terminal (BB 1 here) on the micro-controller, fig 5, and it is this feature which will allow students to solve almost any engineering problem. Once students have learned how to use the transistor as a switch the possibilities are endless. The requirement to assemble logic gates and manage micro-electronics has been removed and replaced by programming and this opens the doors to its use in mathematics and science classrooms where the educational value is huge. At the same time these devices provide the entitlement to the next generation of knowing how their digital world is created. Micro-controllers provide a real STEM solution for today's students.

https://en.wikipedia.org/wiki/File:Epro_theremin_middle_bach.ogg for an example of the sound from a Theremin.

https://education.ti.com/en/resources/stem for support in coding and ideas for project work.

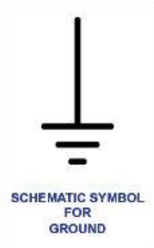
http://www.t3europe.eu/resources/?no_cache=1 for freely available STEM resources

About the author

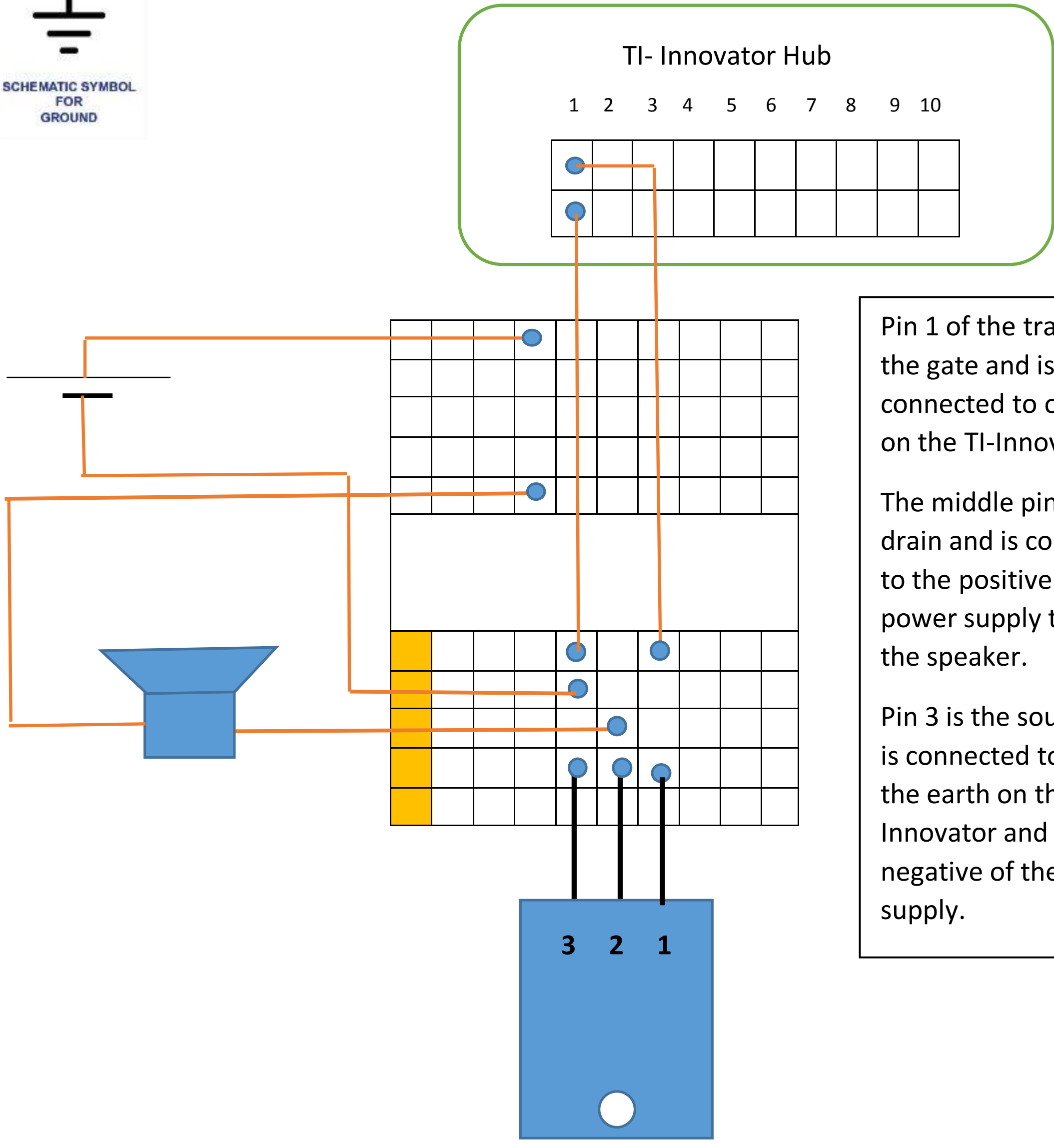
Ian Galloway is the STEM leader for T^3 Europe. He is a former chair of the Association for Science Education and has written several books on physics and STEM teaching. He has been head of science departments in several schools across Europe and still regards himself as a teacher.

T³ EUROPE

Innovator (rounded rectangle) and Breadboard connections for Transistor and Speaker with External Power Supply



The bottom row of Innovator sockets are all connected together to the negative of the supply. This is the “earth” terminal



Pin 1 of the transistor is the gate and is connected to output 1 on the TI-Innovator

The middle pin 2 is the drain and is connected to the positive of the power supply through the speaker.

Pin 3 is the source and is connected to both the earth on the Innovator and the negative of the power supply.

The transistor used, [Z34N](), is shown with the front containing the writing facing upwards. It is a MOSFET power transistor able to handle currents of 10 A. The pin functions arev described above.

Where connections cross over they are not connected.

Each group of 5 sockets (example shaded orange) on the breadboard is connected together. The centre channel is the correct width for accepting chips.