Overview:

You will apply your knowledge of digital output to control a hand-built speaker made from easily obtained materials. The background includes an overview of the physics of electromagnetism and sound. The goal is to play a single tone on the speaker using the TI-Innovator Hub and a TI-Basic program running on an TI-84 Plus™ CE calculator. As an "Extra for Experts", you can choose to write a simple song such as *Happy Birthday* to play through their speakers!

Goals:

1. Apply the principles of electromagnetism to build an electromagnet solenoid using a soda straw and 26 AWG magnet wire.
2. Construct a TTL Power MOSFET circuit controlled by a digital output pin on the TI Innovator Hub to drive a large current from an external 4-AA battery pack through the solenoid.
3. Design an acoustic driver using a coffee cup, a nail, and a magnet.
4. Author a TI-Basic program employing a digital output to play a note or song on the speaker.

Background:

An electrical flow of electrons through a wire, referred to as current (I), creates a magnetic field around that wire. When a long piece of wire is wrapped in loops around a soda straw, the magnetic field produced by each loop, adds to the overall magnetic field from the previously wrapped loops. Lots of loops, so stacked, will produce a sizeable magnetic field.

This magnetic field has a direction or polarity; one end of the field is called the north pole, while the opposite end is called the south pole. If the direction of current flow is reversed in the wire, the polarity of the magnetic field will also reverse. If the current in the wire is stopped, the field will disappear.

When an iron nail is inserted into the center of the soda straw to concentrate the magnetic field, an electromagnet is made. When current flows through the device, a temporary magnet is created from the nail!

Permanent magnets, like the ones on refrigerators, also have a North and South pole; however, the magnetic field is generated by the spins of all the individual electrons in the atoms that makeup the metal of the permanent magnet. All of the spins are held in alignment by the rigid crystalline structure of the metal and all the little magnetic fields from each electron add up, similar to how the fields of each loop in the electromagnet add up. Since the crystal structure is stable, the magnetic field is permanent.

If a permanent magnet is mounted on top of the nail in the electromagnet above, then the fields of the permanent magnet and electromagnet will interact. If the two fields are oriented north/north or south/south, then the two will repel. If they are opposite, they will attract.

To build a speaker, the electromagnet must be turned on and off very fast, this pulsing current will cause the nail to vibrate with the same frequency as the current pulsed through the electromagnet. The TI-Innovator Hub can switch a digital output on and off very quickly; however, it can't produce the current needed to supply the electromagnet. To solve that need, an TTL Power MOSFET can switch the large current flowing from the external 4-AA battery pack into the electromagnet. Then, the TI-Innovator Hub can be used to turn the TTL Power MOSFET on and off if the digital output of BB 1 is connected to the gate of the TTL Power MOSFET.

If the current through the electromagnet is switched on and off 261 times a second or Hz by the TI-Innovator Hub and MOSFET, then the nail will vibrate at 261 Hz. When an air mass driver, such as a Styrofoam cup, is attached to the end of the vibrating nail, the vibrating cup will produce air pressure waves that vibrate at 261 Hz. These pressure waves then move through air as sound and eventually fall upon your ear where they are focused by the outer ear onto the eardrum. This causes the eardrum to vibrate at 261 Hz.

The vibration of the eardrum is then conducted, via the small bones of the middle ear, into the cochlea of the inner ear. As the vibrational energy moves through the turns of this organ, hairs on the surfaces of cells inside the cochlea also begin to vibrate at 261 Hz. These small hairs bend, and electro-chemicals are released at 261 Hz into nerves that create a 261 Hz

signal along the auditory nerve leading to the brain. When the brain receives this signal, it is perceived and recognized as middle C on a piano.

Voila! You have a speaker you can use to play music!

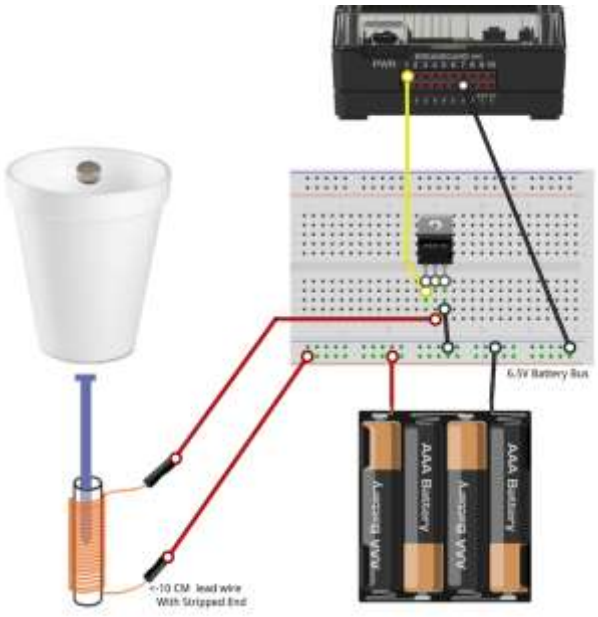
Materials and Tools:

- TI-84 Plus CE
- TI-Innovator Hub with USB Cable
- TI-Innovator Breadboard Pack:
  - Breadboard
  - Male to Male Jumper Cables
  - Male to Female Jumper Cables
  - 4-AA Battery Holder
  - TTL Power MOSFET
- Scissors
- Drinking straw
- Styrofoam cup
- 3/8" neodymium (preferable) or ceramic magnet
- 2 ½" iron nail
- 2 meters of 26 gauge magnet wire
- 4 AA batteries

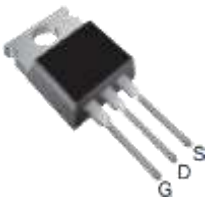
Build the Hardware:

Assemble the circuit in the diagram on the right, following these steps:

1. Tightly wrap the 2 meters of 26 AWG magnet wire around an 8 cm length of soda straw. It is OK for the wraps to overlap. Be sure to leave a ~10 cm of lead wire at the beginning and end of the solenoid wrap.
2. Use sand paper to remove the enamel insulation on the last ~2 cm of each end of the magnet wire. It is important to remove this insulation well to have a good electrical connection in the next step.
3. Insert each of the solenoid stripped lead wires into the female end of a Male to Female Jumper Cable. Use a small piece of tape to secure the stripped magnet wire lead in the receptacle.
4. Insert the TTL Power MOSFET in the breadboard as shown in the diagram.
5. Connect a yellow Male to Male Jumper Cable from BB1 on the breadboard connector of the TI-Innovator Hub to the far left leg (Gate) of the TTL Power MOSFET.
6. Insert one of the Male to Female Jumper Cables from the solenoid into the breadboard column common with the middle leg (Drain) of the TTL Power MOSFET.
7. Connect the other Male to Female Jumper Cable from the solenoid into the positive (red) 6.5V battery bus on the breadboard.
8. Connect a Male to Male Jumper Cable going from the blue ground bus to the far right leg of the TTL Power MOSFET (Sink).



TTL Power MOSFET Diagram



G- gate, D- drain, S- sink

9. Use a black Male to Male Jumper Cable to connect the blue ground on the 6.5V bus to any TI-Innovator Hub ground.
   - The 4-AA battery pack and TI-Innovator Hub must share a common ground.
10. Double-check all connections for accuracy up to this point. Lastly, insert batteries into the 4-AA battery pack and connect the black wire (-) to the 6.5V bus ground (blue) and the red wire (+) to the 6.5V power bus (red).
11. Touch the TTL Power MOSFET to check for heating.
    - If the TTL Power MOSFET gets hot, **immediately** disconnect the 4-AA battery pack and the TI-Innovator Hub. Double-check all connections.
12. Plug the B end of the "unit-to-unit" USB cable into the TI-Innovator Hub and then the A end into the handheld device.
13. Turn on calculator.

Write the Software for the TI-84 Plus CE:

Code for the TI-84 Plus CE:

```
Send("CONNECT SPEAKER 1 TO BB1")
For(N,1,10)
Input "ENTER A TONE FREQUENCY?",F
Send("SET SPEAKER 1 TO eval(F) TIME 5")
Wait 5
End
```

Program Description:

1. Connect SPEAKER 1 to BB1 (the SPEAKER object is a fast digital output)
2. Use a "For loop" to prompt user for a tone (frequency) to play on the speaker 10 times.
3. Play the tone for 5 seconds.

Extra for Experts:

Play Happy Birthday on your speaker. To do this, the program requires two lists of data. The first list (L1) contains the note or rest (such as middle C) while the second list (L_2) contains the note value or the rest value (such as a whole note or a quarter rest). The first list will contain the frequencies of the notes; a rest is a frequency of 0. The second list will contain time durations in seconds for each corresponding note.

{261,0,261,294,261,349,330,0,261,0,261,294,261,392,349,0,261,0,261,523,440,348,349,330,294,0,465,466,440,349,392,349,0}→L_1
{12,1,12,8,8,8,4,16,1,12,12,8,8,8,4,16,16,16,8,8,16,1,16,16,8,4,16,16,8,8,8,4,4}→L_2

The position within the array, called the array index, relates the two lists. In other words, position 7 in L_1 is the note to play while position 7 in L_2 is the duration that note is played.