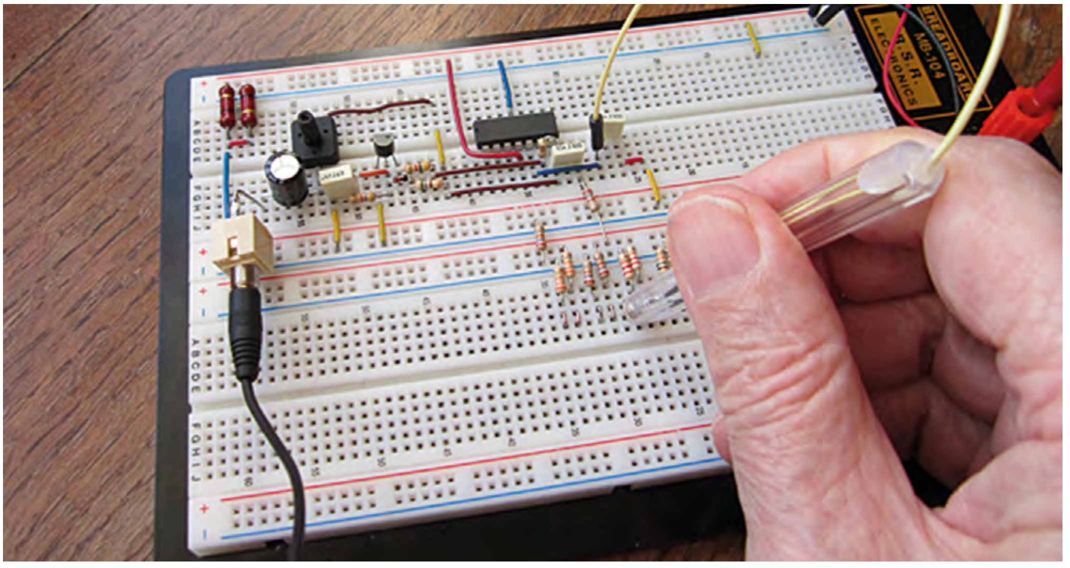
# Make sweet music with the Sineophone

A smooth new take on a favourite electronic music machine

Eric Coates

hsmag.cc/cabTmd

Eric Coates, BSc (Hons) MA has lectured on electronics in technical colleges and acted as examiner and moderator for several UK technical educational boards. He is the founder and CEO of **learnabout-electronics.org**



**Electronic music covers an amazing array of instruments and techniques.** Music created by entirely electronic means began back in the 1930s with instruments such as the Theremin, and continued through the 1960s and 1970s with the much-loved and much-copied Stylophone.

Most of these copies, like the original, used the humble 555 timer to produce square waves of varying frequencies for a musical note that had a harsh sound due to the many harmonics present in square waves.

## THE SINEOPHONE IS BORN

This made me think, "How would it sound if we used sine waves instead of square waves? Perhaps a similar fun instrument, but with a sweeter sound." A Sineophone maybe!

Therefore to begin with, we need a sine wave oscillator that operates at audio frequencies and can be easily tuned to produce the different frequencies required for different notes.

## CHOOSE YOUR OSCILLATOR

Looking at sine wave oscillators, there are a number of standard designs that produce excellent sine waves using capacitors and inductors, but at radio frequencies higher than the required audio range. Audio oscillators mostly use capacitors and resistors.

The basic design of an audio oscillator is illustrated in **Figure 1**, and consists of an amplifier with a feedback circuit that provides positive feedback by connecting the output signal from the amplifier back to its input, so the feedback signal is in the correct phase to add to the signal produced by the amplifier.

The components in the feedback circuit also determine the frequency of the signal produced. The two most popular oscillators for producing sine waves at audio frequencies are the phase shift oscillator and the Wien bridge oscillator. You can learn more at **hsmag.cc/nKZzqy**.

As the phase shift oscillator does not produce particularly well-shaped sine waves, and to alter the frequency of its output requires the values of three

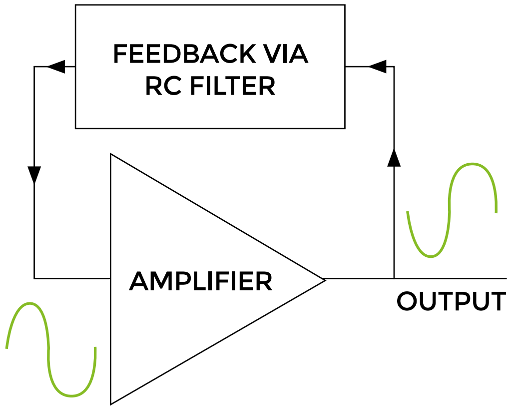



**Figure 1**
An oscillator is basically an amplifier with positive feedback

components to be changed simultaneously, which is tricky, the Wien bridge oscillator, shown in its most basic form below, is our circuit of choice this time.

Controlling the gain of the Wien bridge oscillator is important – the amplifier gain must exactly cancel out the losses in the feedback and frequency control sections of the circuit. There are several ways of ensuring this: the basic Hewlett Packard filament lamp method, or a pair of diodes in the feedback path are both popular methods or, most successfully, using a JFET in place of the filament lamp in **Figure 2**. As the JFET method not only controls the gain as efficiently, but also allows for an output with amplitude, it is basically the circuit shown in **Figure 3** that we will be using for the Sineophone circuit.

Now let's look at the complete Sineophone circuit in **Figure 4**, where it's not as easy to recognise the Wien bridge network. The series capacitor resistor arm of the network is now made up of C3 and R5 (now 27 kΩ) plus the right-hand resistor of one of the resistor pairs on the 'keyboard' at the bottom.

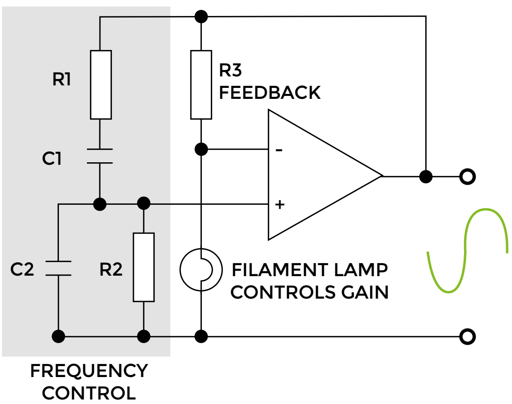



**Figure 2**
The Wien bridge oscillator with an RC network to control frequency and a filament lamp to control gain

## COMPARISON

Take a moment to compare the circuits in **Figures 2** and **3**, and notice that R1 and C1 in **Figure 2** have been swapped around to become C4 and R6 in **Figure 3**. The reason for this is that we will need to change the values of the two resistors in the Wien bridge network for each different note played, and this will be much easier if the resistors R6 and R7 share a common connection as shown in **Figure 3**.

## TAKE A NOTE

When it's powered up nothing is heard, as the Wien bridge network isn't complete. Each note is produced by connecting one pair of equal value resistors on the keyboard to pin 5 of the op amp IC1 via the 27 kΩ resistors R5 and R9 using a contact on the tip of the stylus. The parallel arm of the Wien bridge network now comprises the left-hand resistor of the selected pair in series with R9 (also 27 kΩ), both connected in parallel with C2. The series section of the bridge is now the right-hand resistor of the keyboard pair in series with R5 and C3.

The tip of the stylus bridges the two contacts at the open ends of both resistors of the pair for that note. Now the midpoint of the Wien bridge is momentarily connected to pin 5 (the non-inverting input) of IC1. This completes the oscillator circuit and so a sine wave note is produced. Different notes are produced as different frequencies by using different value resistor pairs for each note. The values of the resistors in each pair are added to the 27 kΩ values of the main Wien bridge resistors R5 and R9. The values of the two 10 nF Wien bridge capacitors C2 and C3 are unchanged over the range of available notes.

## KEYBOARD DESIGN

The prototype Sineophone can produce a scale of eight notes and, for each note, it's first necessary →

## HEWLETT-PACKARD

Although the Wien bridge had been around since 1891, it was not until 1939 that William Hewlett, a student at Stanford University in California, incorporated it into a practical audio frequency sine wave oscillator that has low distortion and a variable frequency and also a stable amplitude. This was achieved by the inclusion of an ordinary filament lamp as the gain control component. In collaboration with fellow student David Packard, the firm of Hewlett Packard was created to manufacture (initially in Dave Packard's garage) a useful, inexpensive, and highly successful audio signal generator.

## YOU'LL NEED

- **Breadboard** with solid and flexible wire links
- **Semiconductors**
  1 × LM324 IC
  1 × 2N3819 JFET
  1 × 1N4148 diode
- **Capacitors**
  1 × 0.47 µf polyester
  2 × 10 nf polyester
  1 × 220 µf electrolytic
- **0.5 W resistors**
  2 × 1 kΩ
- **0.25 W resistors**
  1 × 560 Ω
  2 × 3.3 kΩ
  2 × 4.7 kΩ
  2 × 5.1 kΩ (2 extra 4.7 kΩ used in prototype)
  2 × 9.1 kΩ (2 extra 10 kΩ used in prototype)
  1 × 10 kΩ
  2 × 13 kΩ (15 kΩ used in prototype)
  2 × 18 kΩ
  2 × 22 kΩ
  3 × 27 kΩ
  2 × 33 kΩ
- **Miniature variable resistor**
  1 × 4.7 kΩ
- **1 × headphone socket**
- **Headphones** (approx. 30 Ω)
- **For the stylus**
  An old Bic pen
  A small dome-headed bolt
  Hot glue
- **Power supply options**
- **1 × 9 V battery** (with connector leads)
- **2 × 9 V batteries** (with connector leads, connected in series to give 18 V)
- **12 V DC supply** (and matching connection for breadboard screw terminals)
- **Current requirement** approximately 16–20 mA

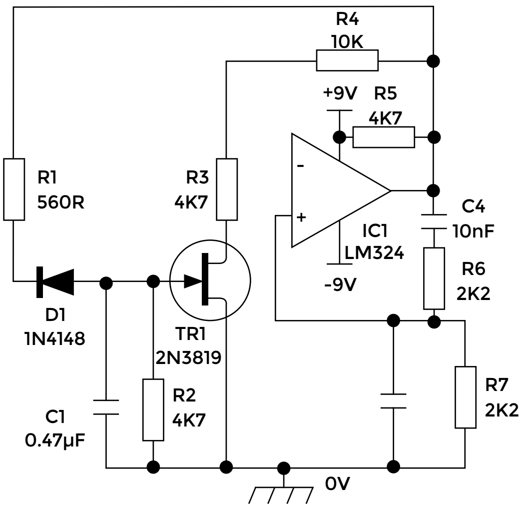



**Figure 3** In the improved Wien bridge oscillator, a JFET acts as a variable resistor to automatically control gain

## MUSIC LESSON

Beginning at the piano note of middle C (C4), the frequencies of the notes in our scale are therefore:

C4 = 261.63 Hz
D4 = 293.66 Hz
E4 = 329.63 Hz
F4 = 349.23 Hz
G4 = 391.99 Hz
A4 = 440.0 Hz
B4 = 493.88 Hz
C5 = 523.25 Hz

to know the frequency of the notes to be used. An eight-note scale has been chosen, assuming that the 'A' note used (A4) is 440 Hz.

No flat or sharp notes have been included but these could also be created, given enough space on your breadboard. Lists of notes and frequencies are available from a number of websites. The frequencies listed above are rounded to two decimal places.

### HITTING THE RIGHT NOTE

To calculate the appropriate resistor values for the Sineophone keyboard we need to know the appropriate formula for producing any particular frequency using the Wien bridge oscillator. The basic formula for the frequency of oscillation is:

$$f_{osc} = \frac{1}{2\pi RC}$$

Therefore the value of R can be found by:

$$R = \frac{1}{2\pi f_{osc} C}$$

…which means a suitable resistance to generate A4 for example from our circuit would be:

**R = 1/ (6.283 × 440 × $10^{-8}$) = 36 172 Ω**

As we will be using standard E24 series resistors, the choice of values is somewhat limited, and because of these limits it is not going to be possible to simply choose a single E24 resistor for each of the chosen notes that gives an absolutely accurate frequency. Any error can be reduced however by using large value fixed resistors for R5 and R9, to take up the bulk of the required resistance value, therefore leaving only the relatively small remaining resistance to be made up by each of the two resistors on the keyboard. So any error in the calculated frequency will only be a certain fraction of this smaller value. Also, bear in mind that each of the E24 series resistors chosen may not be exactly the value indicated by its markings as the actual resistance could vary within its own tolerance limits of +/-5%.

However, the commonly used E24 resistor range only has twelve preferred values to cover each decade of resistances, i.e. 1 to10 Ω, or 10 to100 Ω, or 100 to 1000 Ω etc. and each initial value may deviate by +/-5%. Therefore, by using this range of resistors to cover the eight-note sequence, we can choose from multiples or sub-multiples of the following values:

10, 11, 12, 13, 15, 16, 18, 20, 22, 24, 27, 30, 33, 36, 39, 43, 47, 51, 56, 62, 68, 75, 82, 91

C4 needs 33.8 kΩ so choose 33 kΩ giving a frequency of 265.26 Hz (an error of 3.63 Hz)

D4 needs 27.2 kΩ so choose 27 kΩ giving a frequency of 294.73 Hz (an error of 1.07 Hz)

E4 needs 21.2 kΩ so choose 22 kΩ giving a frequency of 324.81 Hz (an error of 4.82 Hz)

F4 needs 17.6 kΩ so choose 18 kΩ giving a frequency of 353.68 Hz (an error of 4.45 Hz)

G4 needs 13.6 kΩ so choose 15 kΩ giving a frequency of 378.94 Hz (an error of 13.05 Hz)

A4 needs 9.2 kΩ so choose 10 kΩ giving a frequency of 430.15 Hz (an error of 9.8 Hz)

B4 needs 5.2 kΩ so choose 4.7 kΩ giving a frequency of 502.07 Hz (an error of 8.19 Hz)

A5 needs 3.4 kΩ so choose 3.3 kΩ giving a frequency of 525.26 Hz (an error of 2.01 Hz)

## RESISTANCE VALUES

Using the above formula the total resistance values required for each of the eight notes used will be:

**C4 at 261.63 Hz will require 1/ (2π × 261.63 Hz × $10^{-8}$)= 60 832 Ω or 60.8 kΩ**
**D4 at 293.66 Hz will require 1/ (2π × 293.66 Hz × $10^{-8}$) = 54 197 Ω or 54.2 kΩ**
**E4 at 329.63 Hz will require 1/ (2π × 329.63 Hz × $10^{-8}$) = 48 283 Ω or 48.2 kΩ**
**F4 at 349.23 Hz will require 1/ (2π × 349.23 Hz × $10^{-8}$) = 44 573 Ω or 44.6 kΩ**
**G4 at 391.99 Hz will require 1/ (2π × 391.99 Hz × $10^{-8}$) = 40 602 Ω or 40.6 kΩ**
**A4 at 440.00 Hz will require 1/ (2π × 440.00 Hz × $10^{-8}$) = 36 172 Ω or 36.2 kΩ**
**B4 at 493.88 Hz will require 1/ (2π × 493.88 Hz × $10^{-8}$) = 32 225 Ω or 32.2 kΩ**
**C5 at 523.25 Hz will require 1/ (2π × 523.25 Hz × $10^{-8}$) = 30 417 Ω or 30.4 kΩ**

As 27 kΩ of the above values are made up by R5 or R9, so 27 kΩ must be subtracted from these values to find the ideal values for the keyboard resistors:

60.8 kΩ – 27 kΩ = 33.8 kΩ for C4
54.2 kΩ – 27 kΩ = 27.2 kΩ for D4
48.2 kΩ – 27 kΩ = 21.2 kΩ for E4
44.6 kΩ – 27 kΩ = 17.6 kΩ for F4
40.6 kΩ – 27 kΩ = 13.6 kΩ for G4
36.2 kΩ – 27 kΩ = 9.2 kΩ for A4
32.2 kΩ – 27 kΩ = 5.2 kΩ for B4
30.4 kΩ – 27 kΩ = 3.4 kΩ for A5

These calculated errors do not include any differences due to the +/-5% tolerance figure for each resistor so can only be considered to be approximate. Using these values on our prototype does create some audible errors in the sequence of notes; most noticeable on G4, A4 and B4 and, for greater accuracy, it could be an advantage to use some resistors from the closer tolerance E48 range of resistors.

As a general rule, you should try to choose resistors that (combined with the 27K of R5 or R9) give a resulting resistance within 1K or less of the calculated value. Sometimes this may be made possible by adding an extra resistor having a low value to each resistor in the pair, to bring the total resistances for that pair as close as possible to the required result, depending on what your aim is and how pitch perfect you intend to be.

## STYLING THE STYLUS

The stylus is basically just a wire that temporarily connects the two keyboard contacts to the non-inverting input of the op amp. However, to make a good contact between the stylus and both resistors, a small dome headed bolt soldered to the stylus wire should do the job well. However, if you don't want to solder, you could easily fix the wire to the bolt using a matching nut. The main criterion is to use a bolt with a domed or round head, preferably one that is nice and shiny, so as to make a good electrical contact between the two small wire loops on the breadboard. The wire for the stylus is a couple of flexible breadboard links, but any (not too thick) flexible wire would do just as well, so long as it will easily plug into the breadboard.

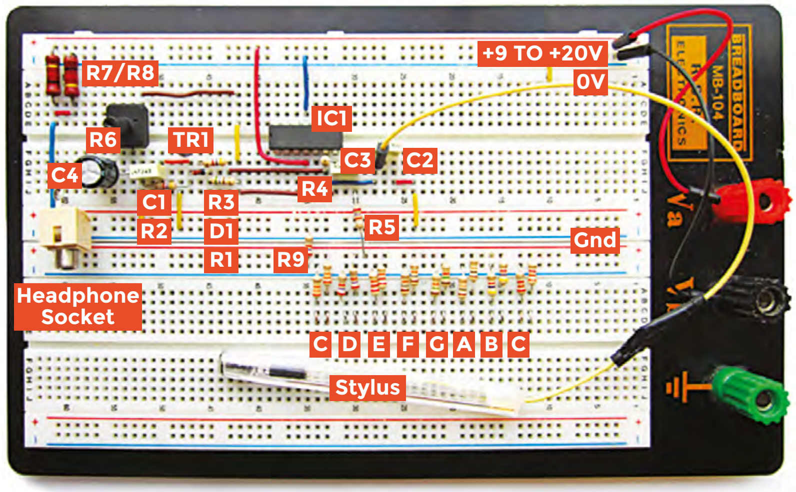
To make the stylus easy to handle, the case of an old ballpoint pen (the cheap kind) was shortened by cutting a small amount from the pointed end, so that it nicely fitted the diameter of the bolt, then cutting off about half of the other end to make it not too unwieldy. Finally, the two ends of the stylus were sealed with hot glue, making sure not to get any glue on the contact surface of the bolt.

## THE POWER SUPPLY

The Sineophone can be powered from any DC supply between 9V and 20V, and requires less than 20mA of current. So, 1 × 9V battery or 2 × 9V to make 18V would be fine, or a handy DC 'Wall Wart' type of supply can be used, 12V seems to be about ideal.

## WANT MORE NOTES?

You may also wish to extend the range of notes on your keyboard, which can easily be done by using the method of calculation described above, for each of the extra frequencies needed.




**Above** The Sineophone layout on breadboard showing the 'keyboard' resistors and stylus

## WANT MORE POWER?

The Sineophone project is intended to introduce a different approach to building a musical instrument, so additions such as extra power amplifiers haven't been included. The output from the JFET-controlled Wien bridge oscillator should be sufficient to drive a pair of headphones (in mono), and a simple volume control (R6) is included to keep the sound level under control. However, it is possible to use the output to drive a power amplifier, for some open air busking. □

**Figure 4** The complete Sineophone circuit, with keyboard and stylus