sine-wave oscillator

very low distortion . . . .

L. Boullart

Nowadays, an entire function generator can be constructed from a few simple ICs. When measuring low-frequency equipment, such as audio amplifiers, it is highly desirable to use a low distortion, reliable sinewave generator.
This particular design is not at all complicated as far as construction is concerned and yet it boasts a distortion level of only 0,01%! Its frequency range extends from 10 Hz up to an inaudible 100 kHz and is very simple to operate.

Where modern HiFi equipment — especially the home-constructed kind — is concerned, accurate measurements are almost impossible to carry out. Although frequency characteristics and squarewave signals can be checked, there is little that can be done towards measuring the actual distortion level, that is, assuming the unit is properly built and the amplifier is working correctly. Fortunately, most up-to-date designs are so good, that the distortion level will be negligible. In any case, it is hardly worth buying an expensive oscillator with an extremely low distortion factor and a first-class distortion meter to carry out one or two measurements.
An oscillator can be built in a number of different ways, each particular design having certain advantages and disadvantages. For low-frequency measurements, where the frequency needs to be varied, it is best to use a 'Wien bridge oscillator'. This type of circuit provides low distortion and allows the frequency to be changed fairly easily with the aid of a stereo potentiometer or a dual-ganged capacitor. The design described here is quite compact and straightforward, but nevertheless it is eminently suitable for measuring frequency characteristics and distortion levels. In addition, a Schmitt-trigger has been included in the circuit to provide squarewave output signals.

The oscillator circuit

Although most readers will probably know how an oscillator containing a Wien network works and have reference books in which they can look it up, it might not be a bad idea to go into the matter here.
Figure 1a shows a network of two resistors and two capacitors. This constitutes the frequency-determining section of the Wien oscillator. If the transfer function is calculated as U_1/U_0, the result will show that there is only one frequency with no phase shift between U_1 and U_0. This will be at the frequency: $F = 1/(2.\pi.R.C.)$. At this frequency the ratio of U_1 to U_0 will be exactly 1:3. If the U_1 voltage is amplified by a factor of three and then fed back to U_0, as drawn in figure 1b, a perfect oscillator is obtained (since the U_1 and U_0 signals are in phase at that particular frequency). Unfortunately, however, there aren't any opamps available with a manufactured gain of three. As figure 1c shows, this does not matter, as the solution is to connect the RC network between the non-inverting input and the output of an ordinary opamp. A voltage divider (R1, R2) is

1

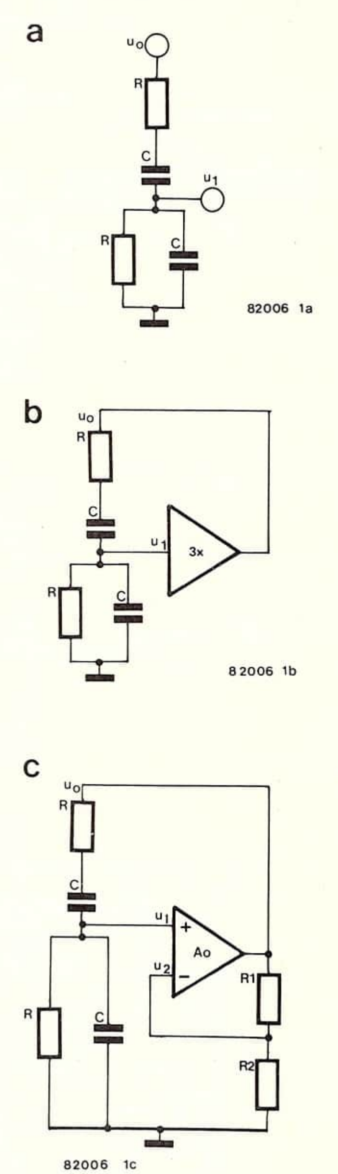

Figure 1. This drawing shows how a Wien bridge can be used to create an oscillator. The voltages U_1 and U_0 will only be in phase for one particular frequency, where U_1 is but 1/3 of U_0. By amplifying the voltage U_1 by a factor of three and feeding it back to U_0, an oscillator can be obtained.

ɪnnected to the inverting input of the ɔamp. The R1/R2 ratio is calculated /ice, so that the amplification factor ll be:

$$A_u = \frac{R1 + R2}{R2} = \frac{2.R2 + R2}{R2} = 3.$$

ıere will now be a sinewave signal at e output of the opamp with a fre- ɹency based on the formula provided ɔove. In practice, the amplification ctor of three is rather critical, since it very difficult to maintain both at the ɔamp side and at the RC network side. the amplification slightly exceeds a ctor of three, the amplifier's output ill produce an everincreasing output ɡnal until this is limited by the supply ıltage. The opamp will then produce a uarewave. If, on the other hand, the nplification factor drops slightly the cillator will either stop operating simply not start in the first place. ıen no output signal will be produced all. Obviously, some sort of control stem is needed to adapt the gain so at the circuit oscillates, without fecting the supply voltage. Only then ill the output be able to produce a mmetrical sinewave signal.

sually, such a control system can be t up by choosing a temperature- ɛpendent resistor for either R1 or R2) hen the output voltage increases, the current passing through the temperature-dependent resistor will also rise, causing its resistance to be altered. As a result, the opamp's amplification will be reduced. If, however, the output voltage drops, less current will pass through the feed-back resistors and so the resistance will change causing the gain to be increased. This method leads to an equilibrium, where the output voltage is constant.

The circuit diagram

Figure 2 shows the circuit diagram for the sinewave oscillator. It looks quite different from the block diagram in figure 1. The opamp here is discrete in structure and consists of transistors T1 . . . T4. The input stage is formed by a cascode circuit containing a bipolar transistor (T1) and a FET (T2). In order to obtain a considerable open loop gain, a Darlington transistor was chosen for T3. By means of the current source formed by T4, the collector is linked to the negative supply voltage.

The bridge section comprising the resistors and capacitors is connected between the collector of T3 and the base of T1. Use has been made of a stereo potentiometer with a logarithmic characteristic to regulate the frequency continuously. Switch S1 acts as a range switch and provides other capacitor values. The four positions provide an overall frequency range of 10 Hz . . . 100 kHz, which amply serves most audio purposes.

The amplitude is stabilised with the NTC resistor R19. The type chosen has a resistance of 1k5 at 25°C. This produces an output amplitude of about 1.5 V_{RMS}. It is very important to use the right type of NTC here, for if the wrong one is used the distortion level will rise alarmingly. The one used here is housed in a glass package with a maximum power dissipation of 20 mW. The latter is vital, as current passing through the NTC has to heat it.

The output signal is fed to P3 by way of C13 and preset P2 (which presets the maximum output voltage). This output level control is followed by an attenuator which has been drawn separately.

Switching S2 connects a Schmitt-trigger in series with the output lead, so that squarewave signals are also available. The Schmitt-trigger consists of transistors T5 . . . T7 and the associated components. As readers can see, the circuit has a standard structure and could have been copied straigth out of a text book. However, the square wave signals it produces are of a high enough quality

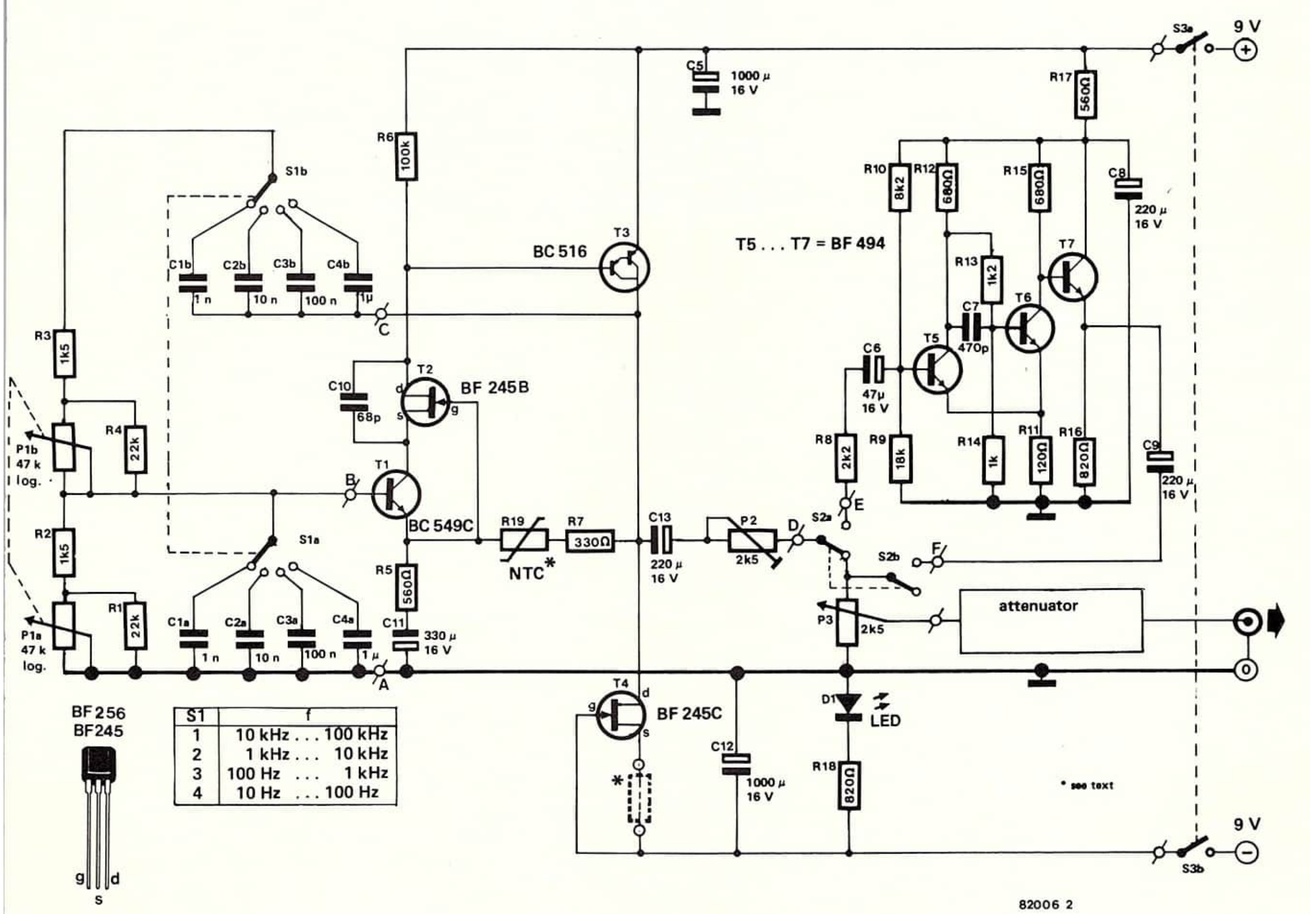

Figure 2. The circuit diagram of the sine-wave oscillator. On the right-hand side a Schmitt-trigger is shown which generates square wave signals. The attenuator is shown in figure 3.

3

a

b

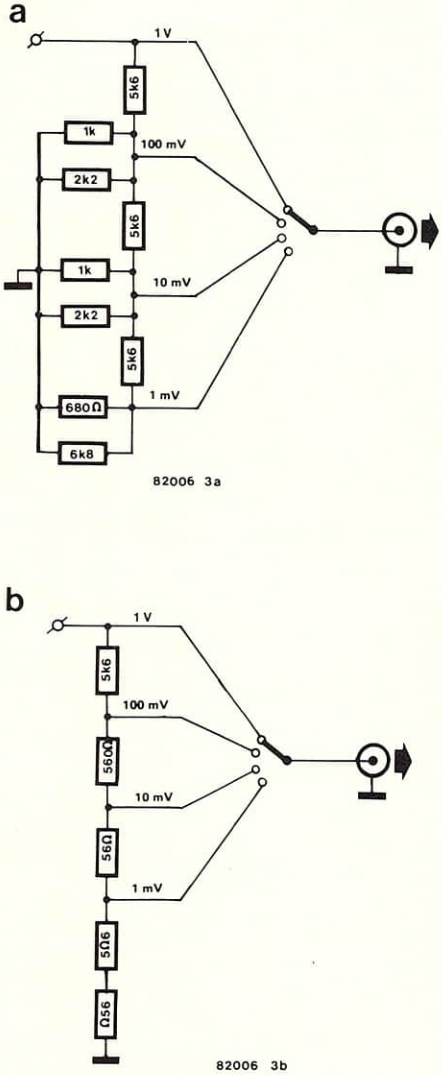

Figure 3. Two different ways in which to build an attenuator. The first version has a constant output impedance of 565 Ω (except when it is set at 1 V), whereas the second has a variable output impedance. The latter version is much more straightforward.

4

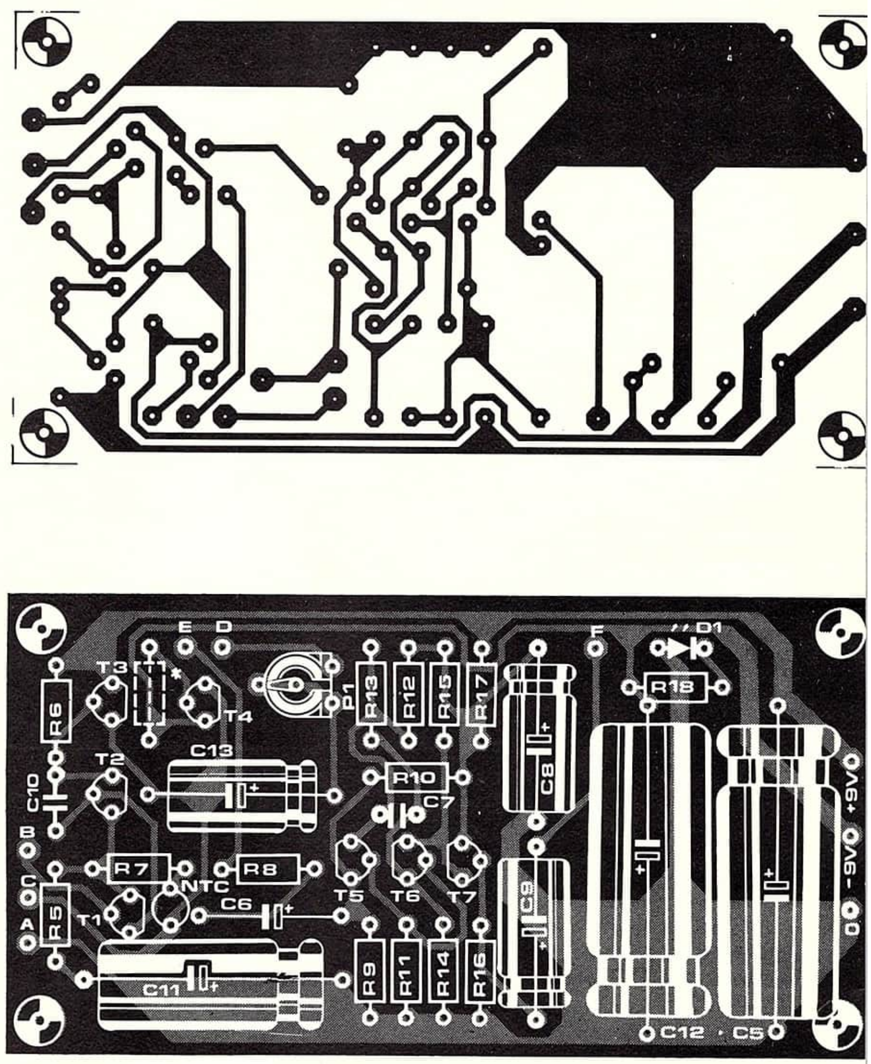

Figure 4. The printed circuit board and the component overlay for the sine wave oscillator circuit. Some of the resistors and capacitors shown in figure 2 are soldered directly to the various potentiometers and switches.

for audio purposes. The only disadvantage involved in the circuit, is that the mark/space ratio is somewhat dependent on supply voltage, although this is really of minor importance in this particular application.

Figure 3 shows two attenuator circuits. Usually signal generators feature an output impedance of 600 Ω. The same can be done here by using the attenuator in figure 3a. In order to obtain an output impedance of exactly 600 Ω for every stage, the resistors will have to have rather "odd" values. If, on the other hand, a slightly irregular output impedance is acceptable, the standard values indicated in the circuit diagram will do. The output impedance will be around 565 Ω. It is only at the highest output level that the impedance will be altered between 0 . . . 5 k (depending on the position of P2 and P3). Provided readers do not require on a standardised output impedance, they can use the attenuator in figure 3b. The output impedance will then of course no longer be constant, but in most cases this does not really matter.

Finally, we still have to mention the LED D1 with its series resistor. This indicates when the oscillator is activated. At the same time, the LED ensures that the circuit's current consumption is equal for both the positive and the negative supply if it is battery-powered. (The current consumption of the LED has been chosen to be the same as that of the Schmitt-trigger circuit.)

Construction and calibration

The easy way out is, of course, to buy the board and the parts from your loca retailer, solder the lot together and Bob's your oscillator. The device wil indeed oscillate, but don't be surprised if it turns out to have a considerabl distortion factor. Obviously, a littl bit more is required. To start with R5 . . . R7 should be metal foil type having a 1% tolerance. The stere potentiometer P1 needs to be a good tracking type. Capacitors C1 . . . C should also be 1% types, if available This is not absolutely essential, but i does lead to an accurate scale divisior for every range. T1 must be a low-nois transistor. Nowadays, various Japanes transistors have an ever lower nois factor than the types mentioned ir the parts list. A good example is the 2SC2546, but unfortunately this type i not yet readily available. In addition ts list

sistors:
,R4 = 22 k
,R3 = 1k5
= 560 Ω
= 100 k
= 330 Ω
= 2k2
= 18 k
0 = 8k2
1 = 120 Ω
2,R15 = 680 Ω
3 = 1k2
4 = 1 k
6,R18 = 820 Ω
7 = 560 Ω
9 = NTC 1k5 at 25°C Philips
/pe 2322 31152
= 47 k log stereo
= 2k5 preset
= 2k5 potentiometer

pacitors:
a,C1b = 1 n
a,C2b = 10 n
a,C3b = 100 n
a,C4b = 1 µ (not an electrolytic type)
,C12 = 1000 µ/16 V
= 47 µ/16 V
= 470 p
,C9,C13 = 220 µ/16 V
0 = 68 p
1 = 330 µ/16 V

miconductors:
1 = LED
= BC 549C, BC 550C
2 = BF 245B, BF 256B
3 = BC 516
4 = BF 245C
5,T6,T7 = BF 494

iscellaneous:
= double pole, 4 position wafer switch
2 = double pole toggle switch
3 = double pole switch

ne voltage at T2 will have to be easured once the circuit has been con- ructed. This transistor should be a pe that has a drain current of 12 µA a gate-source voltage of −3 V (we will ome back to this later). For this reason, might be a good idea to place a tran- stor socket in this position on the oard first.

o get back to building the circuit, part f it is not mounted on the board. This cludes the frequency-determining net- ork at the circuit input (everything quired for connections A . . . C) and ne switch S2 together with potentio- neter P3 and the attenuator.

n the input circuit the capacitors are oldered directly to switch S1 and kewise the resistors R1 . . . R4 to the ereo potentiometer. This section is nen connected to the board by means

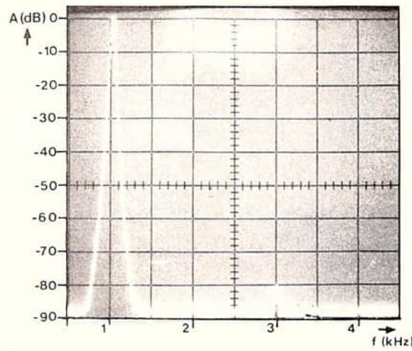

Photo 1. Shown on a spectrum analyser are the oscillator's distortion residues at a frequency of 1 kHz. The first large peak represents the 1 kHz signal. The first even harmonics are at a level of −85 dB with respect to the 1 kHz signal, or rather at 0.006%. The first odd harmonics contribute 0.01% (−80 dB).

of three wires, after the rest of the components have been mounted. Points D . . . F are then linked to switch S2 and potentiometer P3 is wired. Finally, the resistors belonging to the attenuator are mounted straight onto the switch. Then the supply voltage has to be connected up by way of switch S3.

The power supply may be a straightforward mains type, consisting of a small transformer, a bridge rectifier, one or two electrolytic capacitors and two voltage regulators similar to those published previously in Elektor. Current consumption will be about 23 mA.

Seeing as the current consumption is so low, the circuit may also be battery-powered. Using four 'flat' 4.5 V batteries, the lifespan during intermittent use will be a reliable 100 . . . 200 hours.

Figure 4 shows the printed circuit board for the sinewave oscillator. A resistor is indicated by way of a dotted line next to transistor T3 . Once the entire circuit has been built, in the manner described above, a multimeter is connected between the two connections of the dotted resistor and the meter is switched to current measurement (DC!). After the supply voltage has been switched on, the current measured should be about 15 mA. If it is any higher than this, a resistor should be connected in series with the meter and have a value that makes the meter indicate 15 mA. Depending on the result, the resistor or, if not required, a wire link, is soldered onto the board.

The voltage is then measured at T2. Initially this is measured between the source and the gate and then the meter is switched to current measurement and connected to the drain. Several transistors of either the BF 245B or BF 256B type should be experimented with and the one that comes closest to meeting the $V_{GS} = -3$ V and Id = 12 µA requirement is soldered onto the board.

After this the output voltage can be measured. This is usually around 1.5 V_{RMS} (measured at the junction of R7 and C13). If necessary, the output voltage can be altered slightly by choosing another value for R7. Once this has been done, P2 is adjusted so that the output voltage at the wiper of P3 is exactly 1 V_{RMS} when the latter is turned fully clockwise. The attenuator can then be used to select a lower output voltage, 100 mV, 10 mV or 1 mV, which can also be attenuated with the aid of the potentiometer.

If the squarewave signal observed on an oscilloscope screen looks slightly asymmetrical, the solution is to alter the value of R8. Finally a word of advice: the output amplitude can be kept at a constant level by covering the NTC with a layer of insulating material, such as foam rubber.

Easier said than done . . .

This circuit is a perfect example of how an effective device can be built without the need for a lot of ICs or other fancy components. All that the enthusiast has to do is think carefully and decide what the circuit is to achieve and then select the best possible components. The result is a compact design with excellent features. That is exactly how the designer created the prototype which has a distortion level of 0.01% at 1 kHz. The designer even maintains that distortion levels as low as 0.0014% at 1 kHz is possible! The frequency range coveres 10 Hz . . . 100 kHz within 0.15 dB. These are very satisfactory results by any standards. If such a circuit still is not capable of testing a particular audio amplifier, the amplifier must be of such a high quality that there isn't any point in measuring anything anyway!