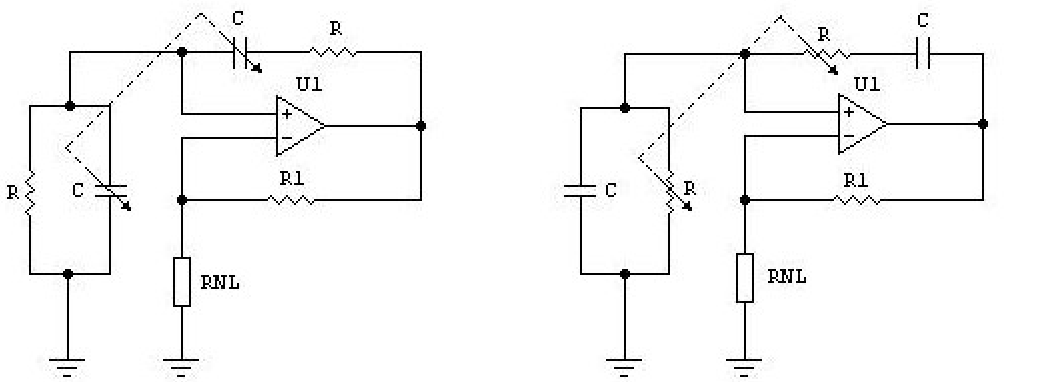
Wien-Bridge oscillator has simplified frequency control

High-quality audio signal generators make extensive use of the Wien-Bridge oscillator as a basic building block. The number of frequency decades covered by these instruments is variable, three being the minimum, and they all cover at least the audible spectrum ranging from 20 Hz to 20 kHz. In addition, frequency can be continuously varied over each decade.

A Wien-Bridge oscillator designed for one decade of continuous frequency control makes use of a two-gang variable capacitor or a two-section variable resistor for frequency adjustment (fig.1). This is the usual approach. However, these are expensive precision components, as accurate tracking between sections is necessary.

In this article, a modified version of the classical circuit that uses a single low-cost variable resistor for frequency control will be described.



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(a) using a two-gang variable capacitor

(b) using a two-section variable resistor

Fig. 1 Frequency control in a typical Wien-Bridge oscillator

Wien-Bridge Oscillator Basics

The typical Wien-Bridge oscillator comprises a differential amplifier having a large open-loop gain (U1 in fig. 1), an R-C network for frequency determination and a non-linear resistive network for amplitude stabilisation. The transfer function of the frequency-sensitive network is:

$$T_+(j\omega) = \frac{j\omega RC}{\left(1-\omega^2 R^2 C^2\right) + 3j\omega RC}$$

for a signal fed back from the amplifier´s output to the non-inverting input. The same signal is fed back from the output to the inverting input, the transfer function for the non-linear network being:

$$T_{-}(j\omega) = \frac{R_{NL}}{R_{NL} + R_1}$$

Loop-gain at unity for oscillations to start requires that:

$$T_{+}(j\omega_0) = T_{-}(j\omega_0) + \frac{1}{A_d} \qquad \ldots(1)$$

where ω_o is the oscillation´s radian-frequency and A_d is the differential amplifier´s open-loop gain. The above equation is satisfied at:

$$\omega_0 = \frac{1}{RC} \qquad \ldots(2)$$

when:

$$\frac{R_{NL}}{R_{NL} + R_1} = \frac{1}{3} - \frac{1}{A_d} \qquad \ldots(3)$$

this is, when:

$$R_1 = (2 + \Delta)R_{NL} \qquad \ldots(4)$$

Δ is given by:

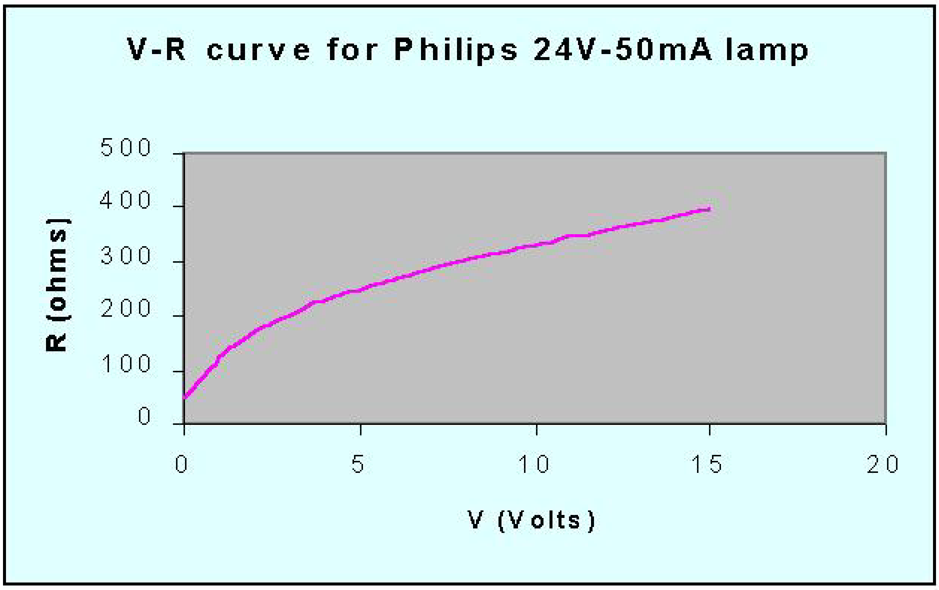
$$\Delta = \frac{9}{A_d - 3}$$

and is in fact a very small number. So, for all practical purposes R_1 equals $2R_{NL}$ at the end of the stabilisation period.

Usually, R_{NL} is a low-power incandescent lamp. Commonly found specifications for this device are 24V-50mA and 12V-60mA, when split power supplies of +12V and –12V are used for the circuit.

The amplitude of the low-distortion output sine-wave can be adjusted varying R_1. R_{NL} automatically adjusts its own value so that eq.(4) is always satisfied. Due to this dynamic action good amplitude and frequency stabilities are attained.

Following is a graph showing the static V-R curve for a Philips 24V-50mA incandescent lamp. The data for this curve was obtained measuring the DC current through the lamp with a set of DC voltages applied and computing R as R = V / I.



For a particular oscillator peak output voltage V_o, the lamp´s voltage drop is calculated as V_o / 3, according to eq. (3). This data is entered to the V-axis on the above graph and a corresponding lamp resistance R is obtained. Equating R_{NL} to this value yields the required R_1 [eq. (4)].

The thermal response of the lamp imposes a limit on the minimum frequency of oscillation if total harmonic distortion (THD) is to be kept below 1%. For this type of lamp the limit is around 20 Hz. Low-distortion operation at lower frequencies can be achieved through the series-connection of two lamps. However, longer stabilisation periods should be expected.

The New Approach

Consider the frequency-sensitive network of fig. 2. We would like to use this network for frequency determination in the Wien-Bridge oscillator. Its transfer function is:

$$T_+(j\omega) = \frac{V_0}{V_{IN}}(j\omega) = \frac{jk_1\omega RC}{\left(1-\omega^2 k_1 k_2 R^2 C^2\right) + \left(k_1 k_2 + k_1 + 1\right) j\omega RC} \qquad \ldots(5)$$

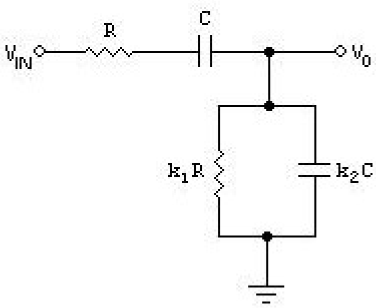


Fig.2 General network for frequency determination

The oscillation´s frequency is now given by:

$$\omega_0 = \frac{1}{RC\sqrt{k_1 k_2}} \qquad \ldots(6)$$

Eq. (5) reduces at $\omega = \omega_o$ to:

$$T_+(j\omega_0) = \frac{k_1}{1 + k_1(k_2 + 1)} \qquad \ldots(7)$$

Again, for oscillations to start eq. (1) must be satisfied. Then:

$$\frac{R_{NL}}{R_{NL} + R_1} = \frac{k_1}{1 + k_1(k_2 + 1)} - \frac{1}{A_d} \qquad \ldots(8)$$

Now, if we let k_2 be a fixed quantity, from eq. (6) we may infer that frequency can be varied over one decade if k_1 changes in a 100:1 ratio. Attempts should be made though to maintain $T_+(j\omega_o)$ constant over the tuning range. This will minimize amplitude variations when the oscillator´s frequency is changed. $T_+(j\omega_o)$ will be approximately constant if:

$$k_1(k_2 + 1) \gg 1$$

or if:

$$(k_2 + 1) \gg \frac{1}{k_1}$$

Letting $k_{1min} = 10$ the result can be easily achieved. Then:

$$T_+(j\omega_0) \approx \frac{1}{k_2 + 1} \qquad \ldots(9)$$

for any frequency setting.

Table I compares exact and approximate values for $T_+(j\omega_o)$, as calculated by eqs. (7) and (9).

TABLE I

	$T_+(j\omega_o)$		
k_2	$k_1 = 1000$	$k_1 = 10$	eq. (9)
0.25	0.7993	0.7407	0.8000
0.5	0.6662	0.6250	0.6666
1	0.4997	0.4762	0.5000
2	0.3332	0.3226	0.3333
10	0.0909	0.0901	0.0909

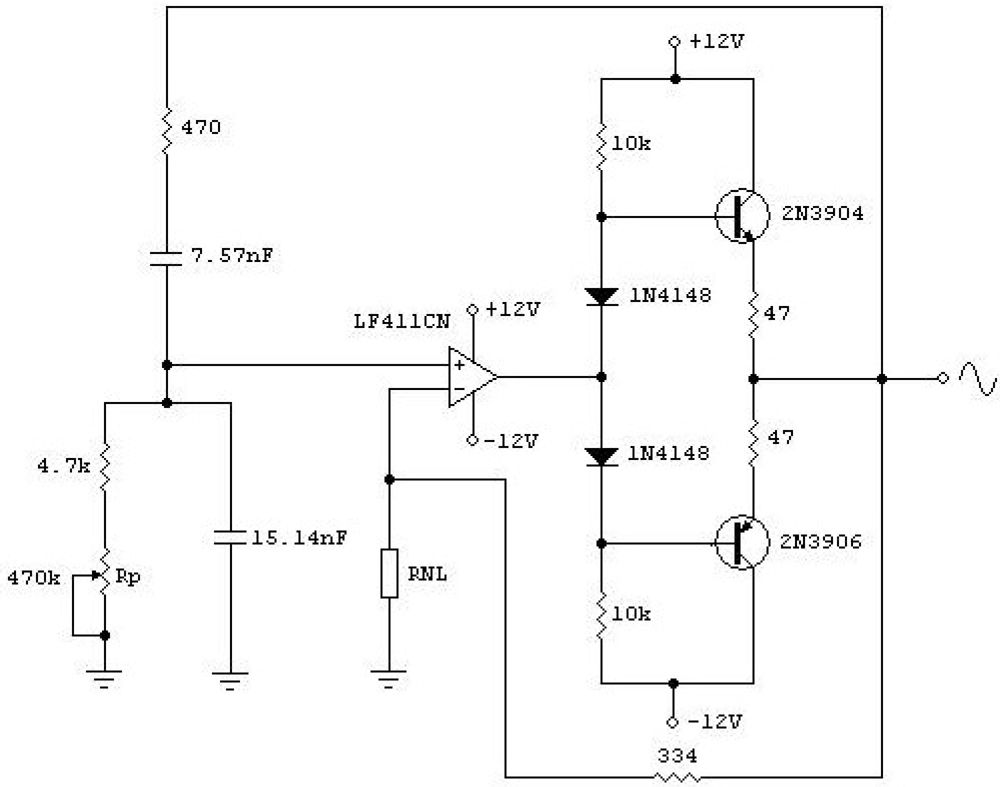
Because the lamp has a positive temperature coefficient, THD, amplitude and frequency stabilities are all temperature dependent. So, some effort has to be spent in figuring out how to minimize room-temperature influences on the circuit. Smaller values for k_2 yield higher working voltages and operating temperatures for the lamp, thus reducing external temperature effects. However, minimal variation of $T_+(j\omega_o)$ over one decade requires larger values for k_2. As a compromise, $k_2 = 2$ or $k_2 = 3$ may be chosen.

If an OP-AMP is selected as the active device, it should be of the low-drift type, for better frequency stability.

Design Example

Fig. 3 shows a Wien-Bridge oscillator with the modification discussed. The oscillator can be tuned from 1 kHz to 10 kHz adjusting R_P. The LF411CN is a JFET-input low-drift type OP-AMP with a typical slew-rate of 15V/us and a typical GBW product of 4 MHz. The NPN and PNP transistors boost the OP-AMP´s output, reducing the signal current drawn from the IC. This effectively contributes to minimize the circuit´s warm-up time.

In this design example, R = 470 ohms and k_1R can be varied between 4.7 kohms and 470 kohms ($k_{1min} = 10$, $k_{1max} = 1000$). A value of $k_2 = 2$ was selected. The oscillator delivers a peak value of 6 Volts or 4.24 Volts RMS. Accordingly, the voltage drop across the lamp is $6/(k_2+1) = 2$ Volts peak. Entering this figure into the lamp´s V-R graph yields a value of 167 ohms for R_{NL}. Then, $R_1 = 2R_{NL} = 334$ ohms. From eq. (6), with $f_o = 1$ kHz, R = 470 ohms, $k_1 = 1000$ and $k_2 = 2$, a value of 7.57 nF is obtained for C. Accordingly, $k_2C = 15.14$ nF. Good-quality capacitors must be selected for C and k_2C for good frequency stability and low THD (some capacitors are very non-linear and temperature-unstable, such as the common low-cost ceramic types. Mylar and NPOs are a good choice).



RNL is a Philips 24V-50mA incandescent lamp

Fig.3 One-decade Wien-bridge oscillator tuned with a single resistive control

Ramon Vargas Patron
rvargas@inictel.gob.pe
Lima-Peru, South America
May 16th 2004