ANALOG DEVICES

Programmable Oscillator Uses Digital Potentiometers

by Alan Li, Analog Devices, San Jose, CA

Digital potentiometers are versatile, and can be used in many filtering and waveform generation applications. This design describes an oscillator where setting the resistance of the digital potentiometers programs the oscillation frequency and amplitude independently. Figure 1 shows a typical diode-stabilized Wien-bridge oscillator that can be used to generate accurate sine waves from 10 k to 200 kHz.
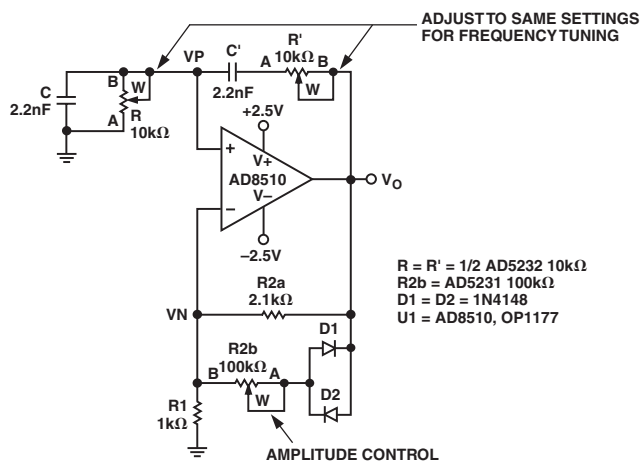

Figure 1. Programmable Wien-Bridge Oscillator with Amplitude Stabilization

In this classic oscillator circuit, the Wien network (R, R', C, C') provides positive feedback, while R1 and R2 provide negative feedback with R2 = R2a∥(R2b + R_{DIODE}). To establish a sustainable oscillation, the phase shift of the loop gain should be zero and the magnitude of the loop gain should be unity. In this circuit, the loop gain, $A(j\omega)\beta(j\omega)$, can be found by multiplying the amplifier gain with the transfer function V_P/V_O. With R = R' and C = C', the loop gain is:

$$A(s)\beta(s) = \frac{1 + R2/R1}{3 + sRC + \dfrac{1}{sRC}} \tag{1}$$

Substituting s = jω and rearranging the real and imaginary terms give:

$$A(j\omega)\beta(j\omega) = \frac{1 + \dfrac{R2}{R1}}{3 + j\left(\omega RC - \dfrac{1}{\omega RC}\right)} \tag{2}$$

Since the phase angle of the loop gain is defined as:

$$phase\ angle = arctan\left(\frac{Im\left|A(j\omega)\beta(j\omega)\right|}{Re\left|A(j\omega)\beta(j\omega)\right|}\right) \tag{3}$$

We force the imaginary term to zero to set the phase shift to zero. As a result, the oscillation frequency becomes:

$$\omega_O = \frac{1}{RC} \ \text{ or } \ f_O = \frac{1}{2\pi RC} \tag{4}$$

where R is the programmable resistance as:

$$R = \frac{256 - D}{256} R_{AB} \tag{5}$$

and D is the decimal equivalent of the digital code programmed in the AD5232. R_{AB} is the end-to-end resistance of AD5232.

To sustain oscillation, the bridge must be in balance. If the positive feedback is too large, oscillation amplitude will increase until the amplifier saturates. If the negative feedback is too large, the oscillation amplitude will be damped out. According to equation (2), the attenuation of the loop gain is 3 at resonance. Thus setting:

$$\frac{R2}{R1} = 2 \tag{6}$$

balances the bridge. In practice, R2/R1 should be set slightly larger than 2 to ensure the oscillation can start. On the other hand, the alternate turn-on of the diodes ensures R2/R1 to be smaller than 2 momentarily and therefore stabilizes the oscillation.

Once the oscillation frequency is determined, the amplitude can be tuned independently by R2b since:

$$\frac{2}{3}V_O = I_D R2_b + V_D \tag{7}$$

R2b can simply be shorted which gives oscillation amplitude of approximately ± 0.6 V. On the other hand, V_O, I_D, and V_D are interdependent variables. With proper selection of R2b, equilibrium can be reached such that V_O converges. However, R2b should not be too large to saturate the output. In this circuit, we applied a separate 100 kΩ digital potentiometer as R2b. By adjusting the resistance setting from the minimum scale to 35 kΩ, we were able to adjust the oscillation amplitude from ± 0.6 V to ± 2.3 V.

Finally, using 2.2 nF for C and C', 10 kΩ dual digital potentiometer with R and R' set to 8 kΩ, 4 kΩ, and 670 Ω, oscillation can be tuned to 8.8 kHz, 17.6 kHz, and 102 kHz respectively with $\pm 3\%$ error (Figure 2). Higher frequency is achievable with an increase in error. At 200 kHz, the error becomes 6%. Although it deviates from the specification, AD8510 was found to be working at ± 2.5 V in this circuit.

Two notes of caution: In frequency-dependent applications, the bandwidth of the digital potentiometer is a function of the programmed resistance. Therefore, care must be taken not to violate the bandwidth limitations. In addition, the frequency tuning in Figure 1 requires that R and R' be adjusted to the same setting. Since the two channels can be adjusted one at a time, an intermediate state will occur that may not be acceptable for certain applications. If this becomes an issue, separate devices can be used in daisy-chain mode so that parts can be programmed to the same setting simultaneously.
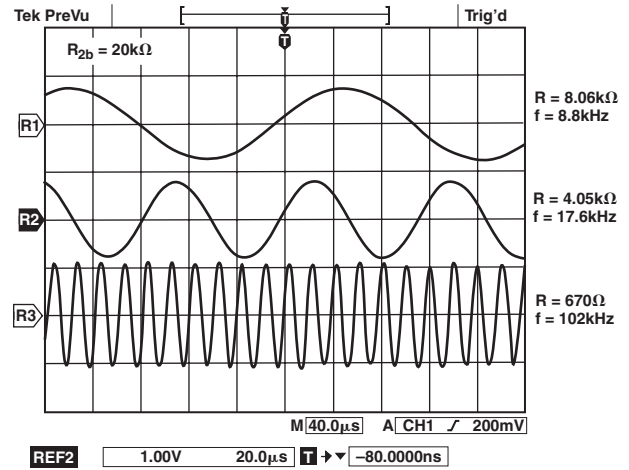

Figure 2. Programmable Frequency

REFERENCES

1. Sergio Franco, *Design with Operational Amplifiers and Analog Integrated Circuits*, Second Edition, McGraw- Hill, 1998.

2. Sedra/Smith, *Microelectronic Circuits*, Fourth Edition, Oxford, 1998.

3. Walter G. Jung, *IC Op-Amp Cookbook*, Third Edition, Prentice Hall, 1997.

REV. 0