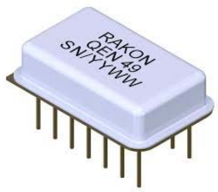
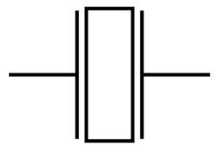
Oscillators

An oscillator is a circuit that produces an ac waveform as output when powered by a dc input.





Frequency

Range of hearing:20Hz to 20KHz.

Frequency and music

NVEnergy: 60Hz.

An Electronic circuit that produces a repetitive, oscillating electronic signal, often a sine wave or a square wave.

Oscillators are used in a lot of applications.

Sometimes, they are called clock (generator).
They can be used to activate processes that are time-dependent, eg. a computer: has an internal clock that is driven by an oscillator.

Most of these oscillators are digital and generate a square wave between 0volts and some positive value (eg. 3.3V or 5V).

Another common use of oscillators is for data communication: a waveform of a certain frequency is generated by an oscillator, and information is super impossed on this electromagnetic wave (modulation).

Other appliances that use waves generated by oscillators are like microwave ovens, radar, synthesizer, clock radio, modem (both digital and analog types), sirens, Christmas lights, ...

Any sequential circuit will have an oscillator.

Oscillators

It is straightforward to imagine a DC voltage source.

One typically thinks of a battery.

But how to make an AC source?

Mains power comes to mind, but that is a single frequency.

This is where an oscillator comes into play.

They are designed to generate an oscillating voltage at a frequency that is often easily changed.

Barkhausen Criteria

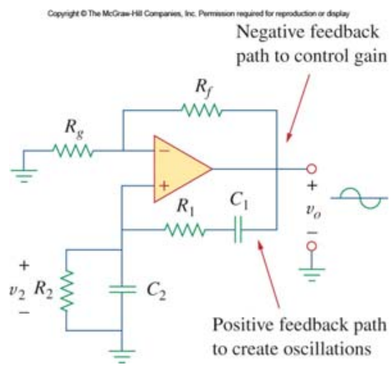
- In order for a sine wave oscillator to sustain oscillations, it must meet the Barkhausen criteria:

1. The overall gain of the oscillator must be unity or greater. Thus losses must be compensated for by an amplifying device.
2. The overall phase shift (from the output and back to the input) must be zero

- Three common types of sine wave oscillators are phase-shift, twin T, and Wein-bridge oscillators.

Wein-bridge

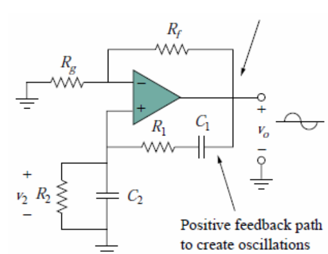
- Here we will only consider the Wein-bridge oscillator
- It is widely used for generating sinusoids in the frequency range below 1 MHz.
- It consists of a RC op amp with a few easily tunable components.



Wein-bridge II

- The circuit is an amplifier in a non-inverting configuration.
- There are two feedback paths:
  - The positive feedback path to the non-inverting input creates oscillations
  - The negative feedback path to the inverting input controls the gain.
- We can define the RC series and parallel combinations as Z_s and Z_p.

$$Z_s = R_1 - \frac{j}{\omega C_1} \qquad Z_p = \frac{R_2}{1 + j\omega R_2 C_2}$$



Wein-bridge III

- The resulting feedback ratio is:

$$\frac{V_2}{V_o} = \frac{Z_p}{Z_s + Z_p}$$

- Expanded out:

$$\frac{V_2}{V_o} = \frac{\omega R_2 C_1}{\omega\left(R_2 C_1 + R_1 C_1 + R_2 C_2\right) + j\left(\omega^2 R_1 C_1 R_2 C_2 - 1\right)}$$

- To satisfy the second Barkhausen criterion, V_2 must be in phase with V_o.
- This means the ratio of V_2/V_o must be real

Wein-bridge IV

- This requires that the imaginary part be set to zero:

$$\omega_o^2 R_1 C_1 R_2 C_2 - 1 = 0$$

- Or

$$\omega_o = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$$

- In most practical cases, the resistors and capacitors are set to the same values.

Wein-bridge V

- In most cases the capacitors and resistors are made equal.
- The resulting frequency is thus:

$$\omega_o = \frac{1}{RC}$$

$$f_o = \frac{1}{2\pi RC}$$

- Under this condition, the ratio of V_2/V_o is:

$$\frac{V_2}{V_o} = \frac{1}{3}$$

Wein-bridge VI

- Thus in order to satisfy the first Barkhausen criteria, the amplifier must provide a gain of 3 or greater.
- Thus the feedback resistors must be:

$$R_f = 2R_g$$

We recall that for a noninverting amplifier,

$$\frac{V_o}{V_2} = 1 + \frac{R_f}{R_g} = 3$$

- Oscillators

Chapter 11: Overview

- This chapter will cover the concept of power in an AC circuit.
- The difference between instantaneous power and average power will be discussed.
- The difference between resistive and reactive power will be introduced.
- Other forms of averaged measurements will be covered
- Apparent power and complex power will also be covered.

Instantaneous Power

The *instantaneous power* *p(t)* absorbed by an element is the product of the instantaneous voltage *v(t)* across the element and the instantaneous current *i(t)* through it.

Assuming the passive sign convention,

$$p(t) = v(t)i(t)$$

It is the rate at which an element absorbs energy.

Instantaneous Power

- This is the power at any instant in time.
- It is the rate at which an element absorbs power
- Consider the generalized case where the voltage and current at the terminals of a circuit are:

$$v(t) = V_m \cos(\omega t + \theta_v) \quad i(t) = I_m \cos(\omega t + \theta_i)$$

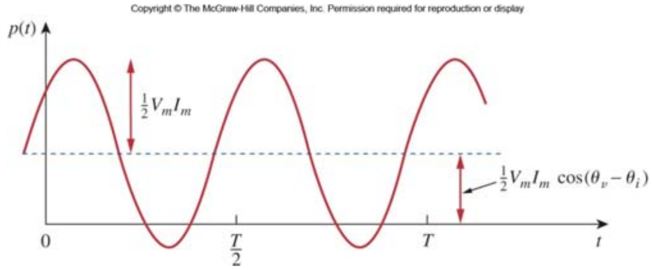
- Multiplying the two together, yields:

$$p(t) = \frac{1}{2} V_m I_m \cos(\theta_v - \theta_i) + \frac{1}{2} V_m I_m \cos(2\omega t + \theta_v + \theta_i)$$

Remember: $\cos A \cos B = \frac{1}{2}[\cos(A - B) + \cos(A + B)]$

Instantaneous Power II

- Note that this has two components.
  - One is constant, depending on the phase difference between the voltage and current
  - The second is sinusoidal with a frequency twice that of the voltage and current.
- A sketch of the possible instantaneous power is below.



Instantaneous Power III

- Note that the figure shows times where the power goes negative.
- This is possible with circuit elements like inductors or capacitors which can store and release energy.
- Note also that instantaneous power is very hard to measure as it is constantly changing.
- The more common power measured is average power.

Average Power

- Average power is the instantaneous power averaged over a period, measured in watts.
- It is given by:

$$P = \frac{1}{T}\int_0^T p(t)\,dt$$

- When evaluated, this returns the component of instantaneous power that was constant.
- The time dependent part is a sinusoid and thus averages to zero.

Average Power II

- In order to get the instantaneous power, you need to work in the time domain.
- But for average power it is possible to work in frequency domain.

In this case, the average power is:

$$P = \frac{1}{T}\int_0^T \frac{1}{2}V_m I_m \cos(\theta_v - \theta_i)\,dt + \frac{1}{T}\int_0^T \frac{1}{2}V_m I_m \cos(2\omega t + \theta_v + \theta_i)\,dt$$

$$= \frac{1}{2}V_m I_m \cos(\theta_v - \theta_i)\frac{1}{T}\int_0^T dt + \frac{1}{2}V_m I_m \frac{1}{T}\int_0^T \cos(2\omega t + \theta_v + \theta_i)\,dt$$

This part is equal to zero

$$P = \frac{1}{2}V_m I_m \cos(\theta_v - \theta_i)$$

$$P = \frac{1}{2}\mathrm{Re}[VI^*] = \frac{1}{2}V_m I_m \cos(\theta_v - \theta_i)$$

Note that *p(t)* is time-varying while *P* does not depend on time.

$$\frac{1}{2}\mathbf{VI}^* = \frac{1}{2}V_m I_m \underline{/\theta_v - \theta_i}$$

Resistive vs. Reactive

- Consider the case when $\theta_v = \theta_i$ the voltage and current are in phase and the circuit is purely resistive:

$$P = \frac{1}{2} V_m I_m = \frac{1}{2} I_m^2 R = \frac{1}{2} |I|^2 R$$

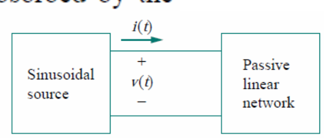
- *When $\theta_v - \theta_i = \pm 90°$*, the circuit absorbs no power and is purely reactive

$$P = \frac{1}{2} V_m I_m \cos 90^\circ = 0$$

Example

$v(t) = 120\cos(377t + 45°)$ V and $i(t) = 10\cos(377t - 10°)$ A

find the instantaneous power and the average power absorbed by the passive linear network of Fig.



Solution:

The instantaneous power is given by

$$p = vi = 1200\cos(377t + 45°)\cos(377t - 10°)$$

Applying the trigonometric identity

$$\cos A \cos B = \frac{1}{2}[\cos(A + B) + \cos(A - B)]$$

gives

$$p = 600[\cos(754t + 35°) + \cos 55°]$$

or

$$p(t) = 344.2 + 600\cos(754t + 35°) \text{ W}$$

The average power is

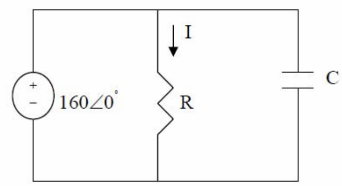
$$P = \frac{1}{2} V_m I_m \cos(\theta_v - \theta_i) = \frac{1}{2} 120(10)\cos[45° - (-10°)]$$

$$= 600 \cos 55° = 344.2 \text{ W}$$

which is the constant part of $p(t)$ above.

Example

A load consists of a 60Ω resistor in parallel with a 90μF capacitor. If the load is connected to a voltage source $v_s(t)$ = 160 cos 2000t, find the average power delivered to the load.



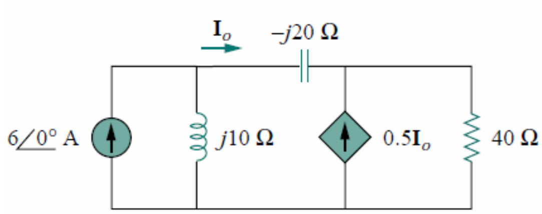
$$90\ \mu F \longrightarrow \frac{1}{j\omega C} = \frac{1}{j90x10^{-6}x2x10^{3}} = -j5.5556$$

I = 160/60 = 2.667A

The average power delivered to the load is the same as the average power absorbed by the resistor which is

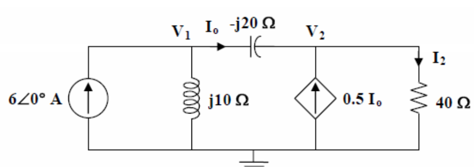
$$P_{avg} = 0.5|I|^2 60 = \mathbf{213.4\ W}.$$

Another Example:



Calculate the average power absorbed by the resistor.

We apply nodal analysis to the following circuit.



At node 1,

$$6 = \frac{V_1}{j10} + \frac{V_1 - V_2}{-j20} \quad V_1 = j120 - V_2 \qquad (1)$$

At node 2,

$$0.5I_o + I_o = \frac{V_2}{40}$$

But, $I_o = \frac{V_1 - V_2}{-j20}$

Hence, $\frac{1.5(V_1 - V_2)}{-j20} = \frac{V_2}{40}$

$$3V_1 = (3 - j)V_2 \qquad (2)$$

Substituting (1) into (2),

$$j360 - 3V_2 - 3V_2 + jV_2 = 0$$

$$V_2 = \frac{j360}{6 - j} = \frac{360}{37}(-1 + j6)$$

$$I_2 = \frac{V_2}{40} = \frac{9}{37}(-1 + j6)$$

$$P = \frac{1}{2}|I_2|^2 R = \frac{1}{2}\left(\frac{9}{\sqrt{37}}\right)^2 (40) = \mathbf{43.78\ W}$$