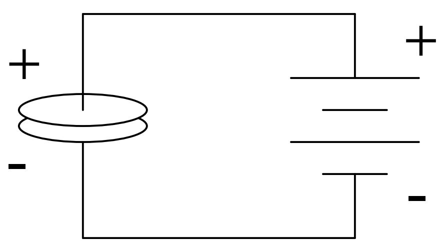
Capacitors

Capacitors are devices which store charge when a voltage is applied. They consist of two conductive plates with an insulating material (the *dielectric*) placed between them. Each lead of a capacitor is attached to one of the plates.

Capacitance is a relative measure of how much charge a capacitor will store:

$$Q = CE$$

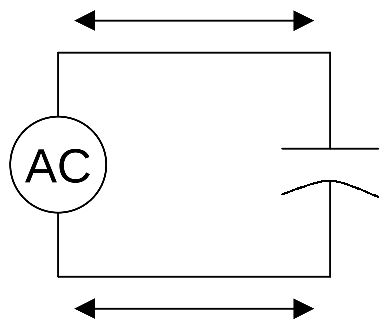
The greater the capacitance C, the more charge Q will be stored for a given applied voltage E. Capacitance is given in units of Farads, while charge has units of Coulombs. (E, of course, is in Volts).

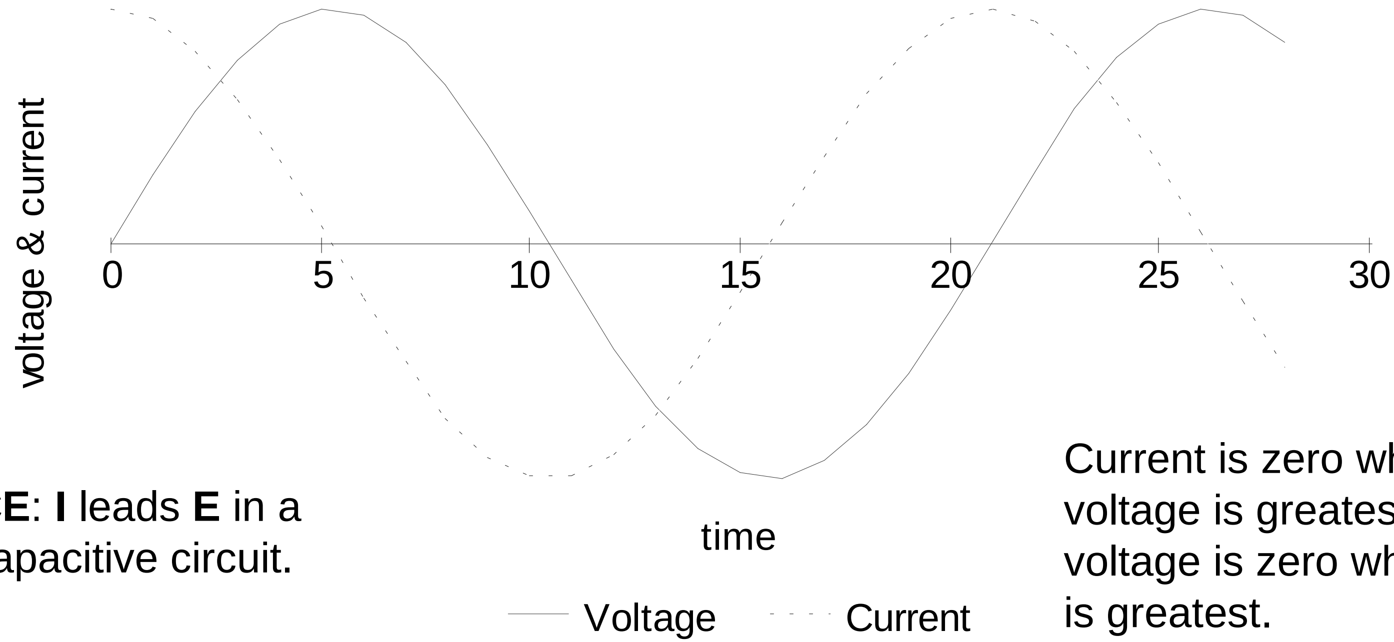


In a DC circuit, the capacitor acts like an open circuit. Current flows in the circuit while the capacitor is charging because electrons are attracted from the positive plate of the capacitor to the positive terminal of the battery, and are repelled by the negative terminal of the battery to the negative place of the capacitor. Charge quits moving once the voltage across the capacitor is the same as the battery's voltage.

Capacitors and AC Signals

In a circuit where the voltage is always changing (AC), the voltage across the capacitor is always changing, and electrons are always flowing toward or away from the plates. This charge movement is really *current* which flows, making the capacitor appear to allow alternating current to flow through it. Capacitors **block** DC but **pass** AC.





ICE: **I** leads **E** in a **C**apacitive circuit.

Current is zero when the voltage is greatest, and voltage is zero when current is greatest.

Ohm’s Law for AC Circuits

Capacitors in AC circuits allow current to flow, but they do not act like short circuits. Capacitors both pass and limit current. Their ability to pass current depends on the frequency of the signal, and is called *reactance*.

$$X_C = \frac{1}{2\pi f C}$$

X_C is capacitive reactance, in ohms
f is frequency, in Hz (or MHz if C is in μF)
C is capacitance, in F (or μF if f is in MHz)

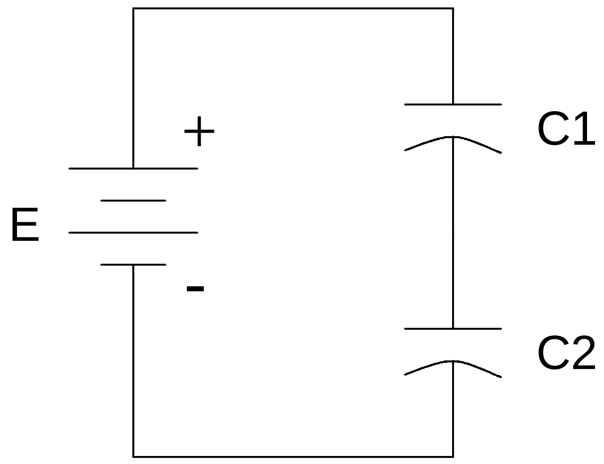
Energy is not lost due to reactance (like it is to resistance). Instead, the energy is stored in the electric field of the capacitor when charged, and released to the circuit as current when discharged.

To find the current in a capacitor for an applied voltage E, we use **Ohm’s Law for AC circuits:**

$$E = IX$$

X is the reactance of the capacitor. Remember that in a capacitor, E and I are out of phase by 90 degrees (one-fourth of a cycle), so E and I do not have these values at the same instant in time.

Combinations of Capacitors



Capacitors in series are like resistors in parallel:

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

Voltage across a capacitor is inversely proportional to its capacitance:

$$E_1 = E\frac{C}{C_1}$$

Capacitors in series can serve as voltage dividers, just like resistors

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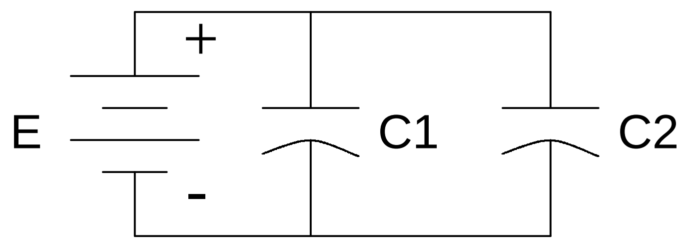


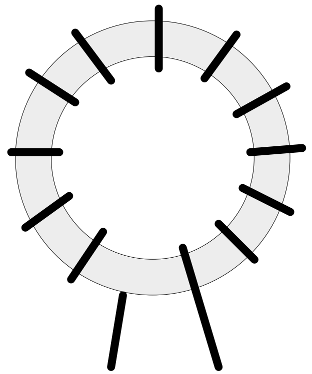
Capacitors in parallel are like resistors in series:

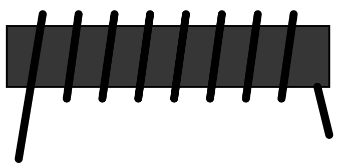
$$C = C_1 + C_2$$

Each capacitor has the same voltage across it:

$$E = E_1 = E_2$$

Inductors


Toroidal inductor


Solenoid

Inductors are loops or coils of wire, usually wound around an iron core. When current flows through an inductor, a magnetic field is created in the core. This magnetic field stores energy. When the current decreases, the magnetic field gives up its energy as current to replace some of the decrease.

Inductors possess a characteristic known as *inductance,* which measures its ability to oppose a *change* in the current flowing through it. Placing an inductor in an AC circuit limits the rate at which current will change. Inductance has units of Henries.

The value of inductance is affected by the size of the inductor, the number of turns, and the material used for the core.

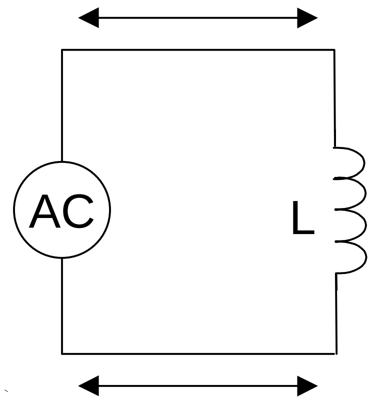
Just like capacitors, inductors possess reactance:

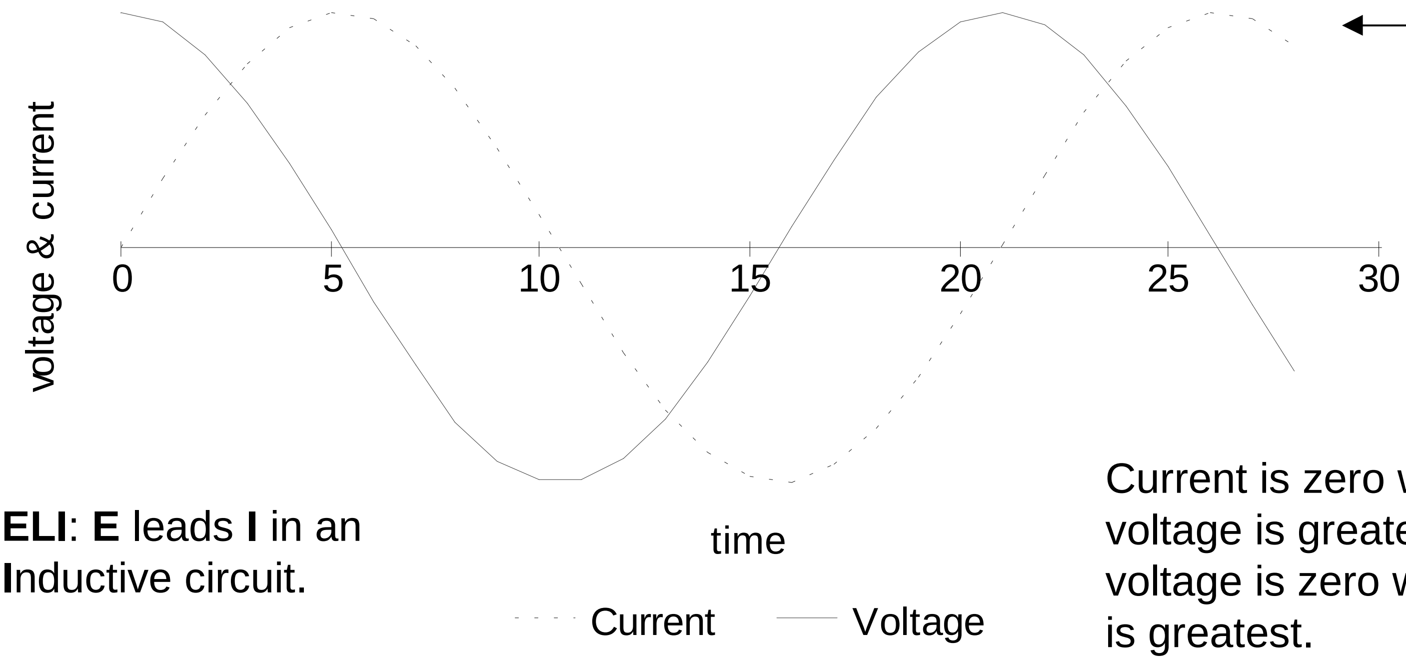
$$X_L = 2\pi f L$$

Ohm’s Law for AC circuits can be used for inductors, just like it is used for capacitors.

Inductors and AC Signals

In a circuit where the voltage is always changing (AC), the voltage across the inductor is always changing, and current flows back and forth through the inductor. The inductor both passes and limits the current flowing through it.

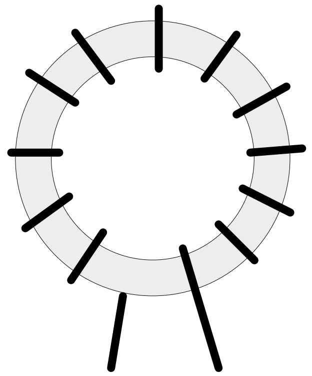




ELI: **E** leads **I** in an **I**nductive circuit.

Current is zero when the voltage is greatest, and voltage is zero when current is greatest.

Toroidal Inductors



Toroidal inductors are frequently used in radio kits because they are compact and easy to make. The cores are either ferrite or powdered iron, depending upon the inductance needed.

Toroid cores have three part identifiers: FT-37-43

- **FT** for ferrite, or **T** for powdered iron
- inside diameter, in hundredths of an inch
- the type of material in the core

Ferrite cores have a higher *permeability*, meaning they'll give you more inductance per turn of wire than will powdered iron cores. Powdered iron cores have a more stable permeability, though. The number of turns N is computed using the equations below.

For powdered iron cores:

$$N = 100\sqrt{L(\mu H) / A_L}$$

For T-50-6 (yellow core), A_L is 40 µH/100 turns
For T-37-2 (red core), A_L is 40 µH/100 turns
(cores are color-coded by material type)

For ferrite cores:

$$N = 1000\sqrt{L(mH) / A_L}$$

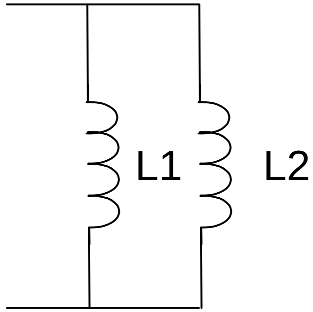
For FT-37-43, A_L is 420 mH/1000 turns
(ferrite cores aren't usually painted)

Combining Reactances

Like reactances combine just like resistors:

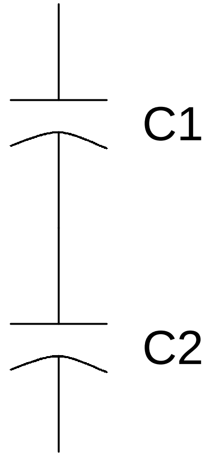
Parallel reactances:

$$X = \frac{X_{L1} X_{L2}}{X_{L1} + X_{L2}}$$



Series reactances:

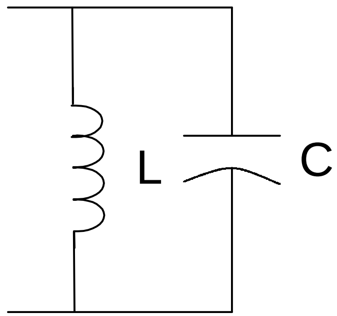
$$X = X_{C1} + X_{C2}$$



Unlike reactances combine differently. These are examples of ***tank circuits*** (circuits having an inductor and capacitor):

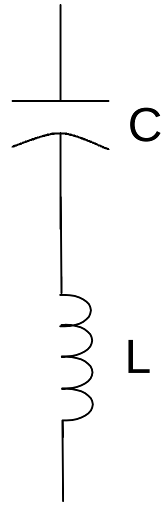
Parallel reactances:

$$X = \frac{-X_L X_C}{X_L - X_C}$$



Series reactances:

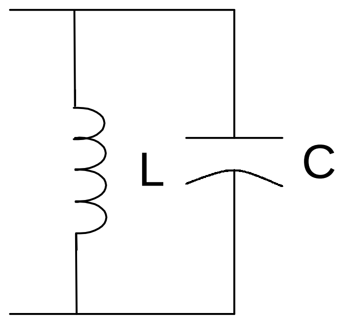
$$X = X_L - X_C$$



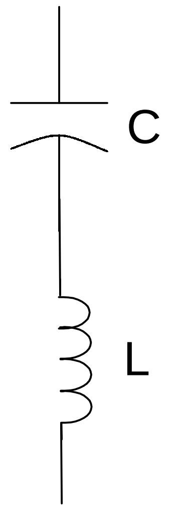
Tank Circuits

Tank circuits are simply circuits containing a capacitor and an inductor, either in series or in parallel.

$$X = \frac{-X_L X_C}{X_L - X_C}$$



$$X = X_L - X_C$$



What happens when the reactances of the inductor and capacitor are equal?

- the reactance of the parallel circuit becomes infinite, and no current would flow in the circuit

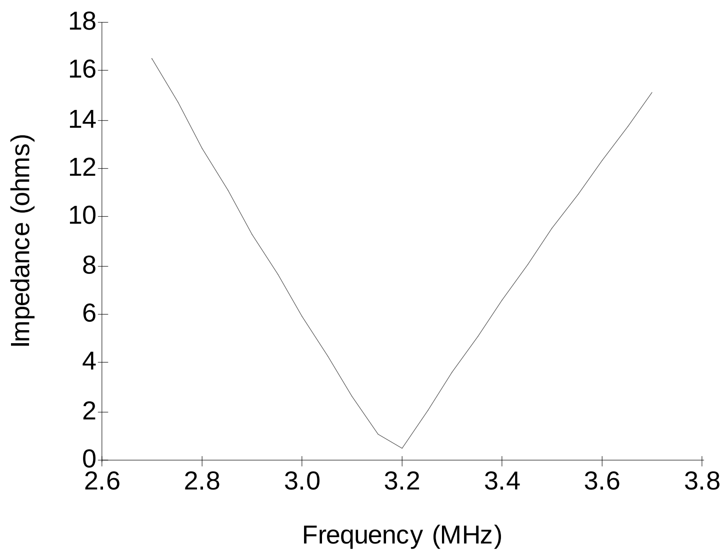
- the reactance of the series circuit becomes zero, and current would flow freely in the circuit

Tank Circuit Resonance

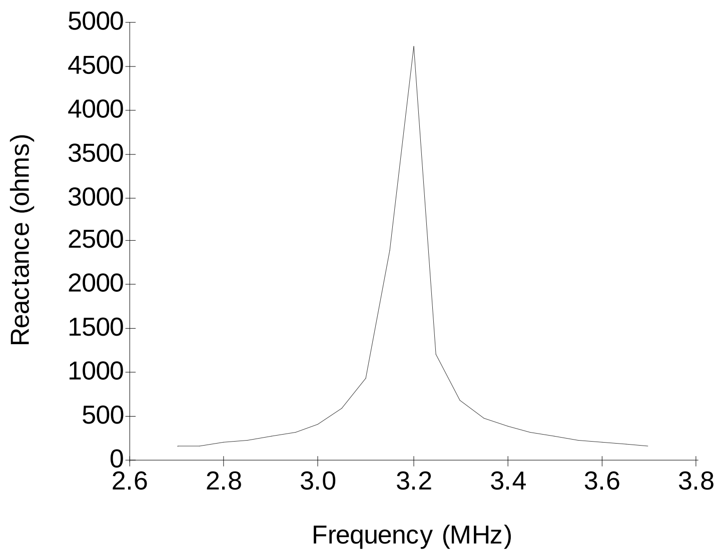
When inductive and capacitive reactances in a tank circuit are equal, the circuit is said to be ***resonant.***

$$2\pi fL = \frac{1}{2\pi fC}$$ gives the resonant frequency: $$f = \frac{1}{2\pi\sqrt{LC}}$$

Series LC circuit:



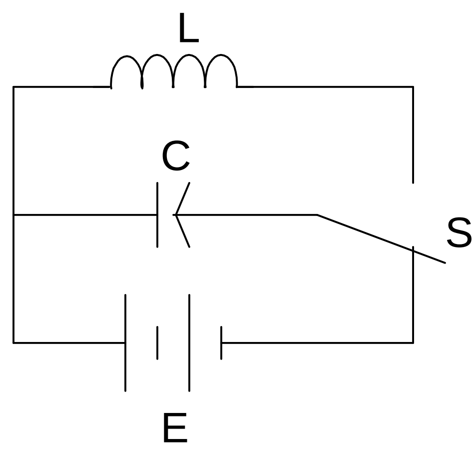
Parallel LC circuit:



Oscillators

An ***oscillator*** is a source of an AC signal.

Consider the circuit at right. When the switch is in the down position, the capacitor is charged by the battery. Once the capacitor is charged, the switch is moved so that the inductor and capacitor are connected. The capacitor begins to discharge, causing a current to flow through the circuit. The inductor limits how quickly the current can flow, though, and the magnetic field in the inductor becomes stronger as the current increases.



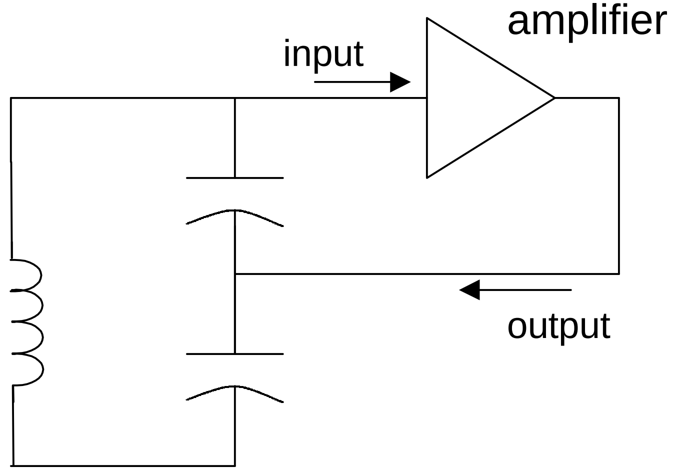
Once the capacitor is discharged the current wants to stop flowing, but the inductor then begins to use the stored energy in the magnetic field to keep the current flowing, causing the current to diminish slowly rather than all at once. This causes the capacitor to charge back up (but with the opposite polarity than before) until the current finally ceases and the capacitor is charged. Then what happens? The capacitor begins to discharge, and the cycle begins again in the other direction! The circuit is said to be *oscillating*.

In real life, the oscillations in this circuit would rapidly go to zero. Why?

Feedback

In order to combat the resistive losses in the oscillating circuit, a portion of the signal is taken from the circuit, amplified, and fed back to the circuit. Two conditions must be fulfilled in order for oscillation to continue:

1) The feedback must be in phase with the original signal
2) The gain due to feedback must be equal to or greater than the resistive losses



What will be the frequency of the oscillator?

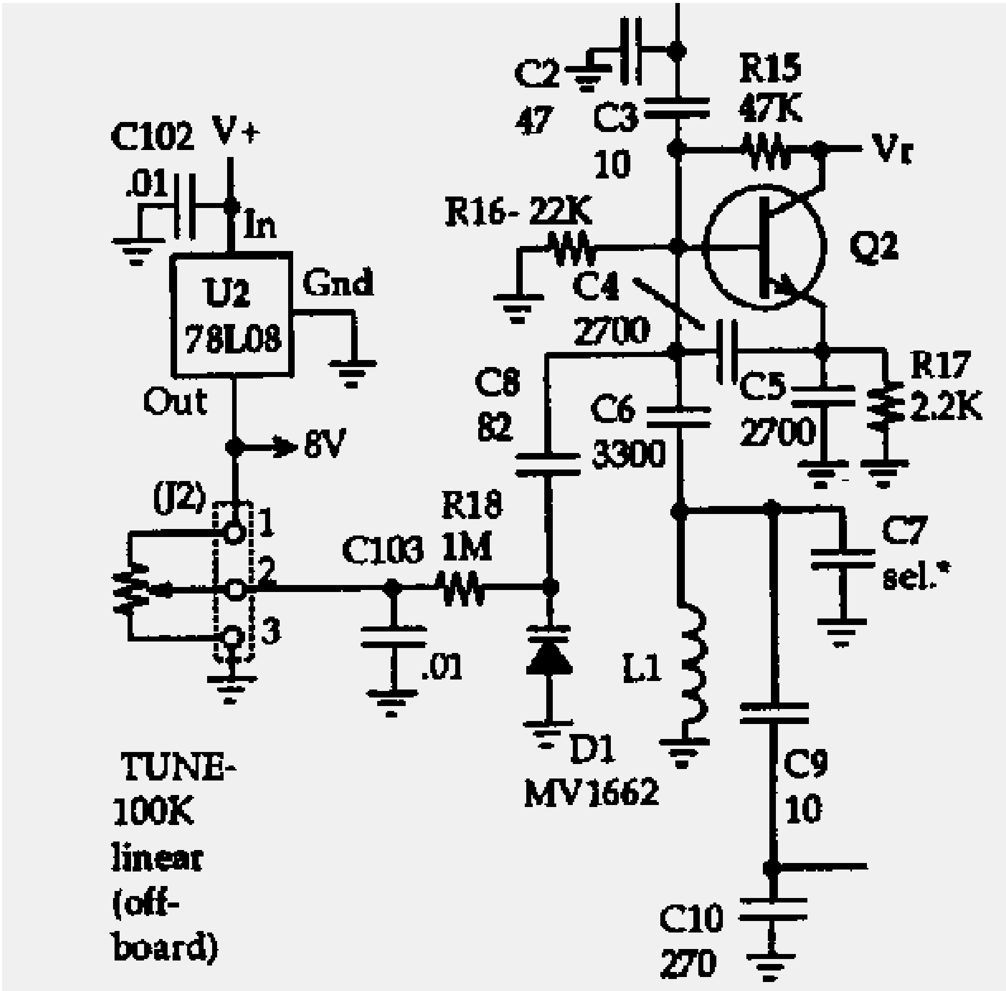
$$f = \frac{1}{2\pi\sqrt{LC}}$$

The SW+40 VFO

The following components make up the LC circuit which determines the frequency of the oscillator: C2, C3, C4, C5, C6, C7, C8, C9, C10, D1, and L1. The value of C7 is chosen so that the oscillator has the right frequency.

D1 is a *varactor diode*. When reverse biased, it has a capacitance which varies with the bias voltage. Its capacitance *decreases* with *increasing* bias voltage. Varying the voltage with the tuning pot causes the frequency of the oscillator to change.

Q2 and resistors R15, R16, and R17 make up the amplifier which supplies feedback to the oscillator.



Circuit copyright 1998 by NN1G.

Construction

- Install the following parts:
  - C2-C6, C8-C10, C103
  - D1, D2
  - L1
  - Q2
  - R15-R18
  - J2 three-pin connector and wiring harness with 100K potentiometer
- Apply power and use frequency counter to test for ~3 MHz signal at base of Q2. If you don’t have a frequency counter, use a general coverage receiver (use a clip lead for the antenna, lay the lead close to the SW+40 board, and tune in the signal like it was a CW signal).
- Test range of VFO by adjusting the tuning pot (note: increasing the value of C8 will increase the frequency range of the VFO)