THE SUPERHETERODYNE RECEIVER

A superheterodyne radio consists of four main parts, an oscillator, a mixer, an intermediate frequency amplifier, and a detector. The signal picked up by the antenna and the oscillator signal are fed into the mixer, where the oscillator and signal frequencies are mixed. The output of the mixer consists not only of the signal and oscillator frequencies, but frequencies of the sum and difference of these frequencies.

An intermediate frequency amplifier strengthens signals of a certain frequency (conventionally 455 kc) and eliminates all others. The output of the mixer of a superheterodyne receiver is fed into the I.F. (intermediate frequency) amplifier. If any one of the outputs of the mixer happen to have a frequency of 455 kc, it is amplified by the I.F. amplifier and fed into the detector.

The detector is usually a diode, which changes the I.F. signal into D.C. The strength of this D.C. depends on the strength of the I.F. signal; both change with the strength of the original signal. The varying D.C. can be used to run an earphone or an audio amplifier.

The radio in this project has a 455 kc I.F. amplifier that has too much regeneration. The I.F. amplifier oscillates weakly. This oscillation mixes with the carrier frequency of the I.F. signal at the detector. The output contains not only the program material, but also a very annoying squeal.

This project is built on two printed circuit boards and contains six transistors.

THE SUPERHETERODYNE

Receiver

ATOMS AND RADIO PARTS

Radios have become very commonplace in our society. They have become so commonplace that we often forget that there was a time when there were no radios.

To understand how radios work, and the shortcomings of this radio, we must first understand the atom.

Everything around you is composed of atoms. The air, this paper, everything. Atoms are composed of very many particles. The most important of these are the proton, the neutron, and the electron. Some of these particles have a charge. Some have weight.

What is a charge? Have you ever walked across a carpet, touched something metal and gotten shocked? Before you touched the metal you had a charge.

There are two kinds of charge, positive and negative. These charges exert force on similar and opposite charges by either attraction or repulsion. Like charges repel, opposite charges attract (just like magnets). Protons are positively charged, electrons are negatively charged, and neutrons have no charge.

To measure the weight or mass of particles, it is necessary to have a unit of weight. Pounds and grams are much too big. A more appropriate unit is a unit with the weight of a proton, the atomic unit. Following is a chart showing the charges and weight of particles:

Particle	Charge	Weight
Proton	Positive (+)	1 atomic unit
Neutron	None	1 atomic unit
Electron	Negative (-)	0 (weight of Little significance)

Suppose we bring a proton and an electron close to each other. Because they have opposite charges, they attract each other. Instead of meeting, they orbit each other. The proton, being much heavier, stays (about) in one place and the electron swings around it. This orbiting system is similar to the earth and the sun, with the electron being the earth, and the proton being the sun. This system is the hydrogen atom--the simplest atom. Normal hydrogen contains no neutrons.

Protons and neutrons, when near each other, have a very strong attraction for each other. If we shoot a neutron into hydrogen, the neutron will join the proton in the center of the atom. We now have heavy hydrogen.

The center of an atom is called its nucleus. The nucleus contains all of the atom's protons and neutrons. Atoms are named by the number of protons in the nucleus.

Suppose we add another proton to the nucleus. Now the nucleus has two protons, and one neutron. The attraction of the protons to the neutron keeps the protons from repelling each other. Because it takes two negative charges to neutralize two positive charges, the atom attracts some neighboring electron into orbit around the nucleus. This is an uncommon type of helium atom. Most helium contains two neutrons.

How can a nucleus with more than one proton hold together? The protons repel each other, so the nucleus should explode. But because neutrons and protons have a strong attraction for each other, the repulsion is overcome. To hold together, a nucleus must have about the same number of neutrons and protons.

The number of protons in a nucleus determines the number of electrons orbiting: 2 protons, 2 electrons; 5 protons, 5 electrons; 103 protons, 103 electrons.

In the helium atom, the two orbiting electrons are about the same distance from the nucleus.

Suppose we add a third proton, the required number of neutrons, and a third electron to the helium atom. We now have a lithium atom.

Instead of taking an orbit, the same distance from the nucleus as the other two electrons, the new electron takes an orbit considerably further away from the nucleus than the two old electrons. This electron is loosely held because it is further away from the nucleus than the other two and it is shielded from the electric field of the nucleus by the innter electrons. That means a small amount of energy can eject this electron into space.

The orbit levels that electrons take are called shells. There are many shells of electrons in heavy atoms.

Here is a chart to show what each shell can hold (in electrons):

Shell No.	1	2	3	4	5
No. Electrons	2	8	8	10	8

(This approximation of shell capacities is good enough, so there is no need to explain subshells).

Suppose we have an atom of sodium which has 11 protons and 11 electrons. Shell 1 is full with 2 electrons, shell 2 is full with 8 electrons, and shell 3 contains only 1 electron. Because of the shielding of the inner electron shells, this electron is very loosely held.

Both lithium and sodium have only one outer electron, which is loosely held. Any atom with few electrons in the outer shell will have loosely held electrons.

On the other extreme, chlorine is an atom with 17 protons and 17 electrons. Its first two shells are full, its third shell nearly so. Not only does chlorine have a very strong hold on its own electrons, but under proper conditions, it can bring another electron into its orbit. Any atom with a shell nearly full will try to complete its shell by absorbing electrons.

Why do some materials conduct electricity? Suppose we have a bar of solid copper. Copper is a metal with loosely held electrons. If we put a voltage on this bar by removing electrons from one end of the bar, and adding electrons to the other end, the extra electrons on the electron surplus end will begin moving toward the electron deficient end. Inevitably, they will collide with copper atoms. Their energy is simply transferred to a loose electron of the copper atom. This electron is ejected from the copper atom with the same speed and direction as the colliding electron. The colliding electron, having no energy to escape from the copper atom, is absorbed. The ejected electron collides with another copper atom and so on. In this way electrons are moved very rapidly across the copper bar.

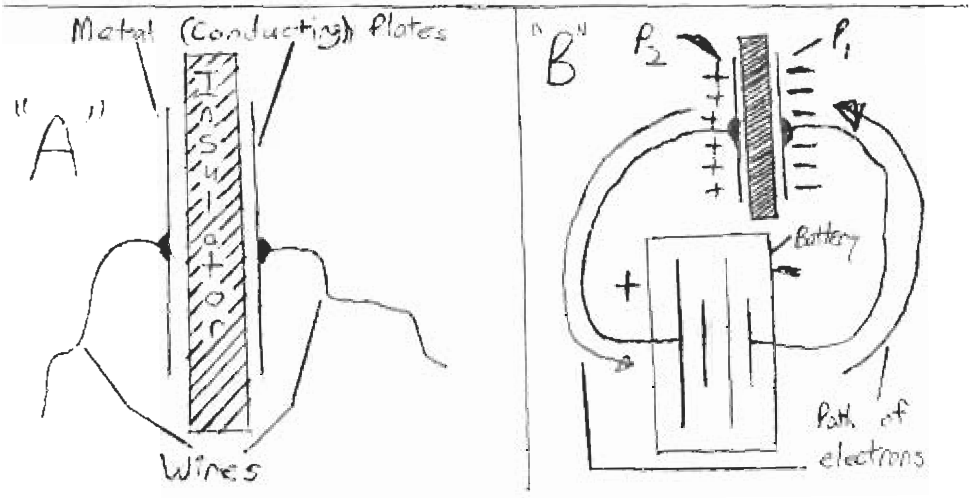
What happens if we try to move electrons through a material with tightly held outer electrons? Electrons begin to move from negative to positive as before. When an electron collides with an atom, it bounces off, or it may even by absorbed. The tightly bound electrons cannot be ejected easily. Little or no current flows.

What happens if you mix a substance with loosely bound electrons "L," with a substance with a tightly bound, incomplete outer shell "T"? Electrons(s) are transferred from atom L to T. L being positively charged from the loss of electron(s) and T being negatively charged from the gain of electron(s) are attracted to each other. We now have an ionic salt. This kind of bond is called an electrovalent bond.

Another type of reaction might take place under conditions discusses in the last paragraph. The electron transfer begins as before. This time, there isn't enough force to complete the electron transfer. The atoms, being attracted to this electron are bounded together. This is called sharing of electrons. Electrons are always shared in pairs. This type of bond is called a covalent bond. Also if two atoms have equal attraction for each other's electrons, a covalent bond may be formed. That means an atom may form a covalent bond with another atom of its own type.

Suppose we place two conducting metal plates next to each other, connect a wire to each plate, and insert an insulating (non-conducting) material between them ("A: below). This device is called a capacitor. A battery is a source of electricity. It is like an electron pump. It pumps electrons from its positive pole (+) to its negative pole (-). If a capacitor is connected to a battery ("B") above, electrons from the negative pole of the battery flow into P_1, making it negatively charged. The negative charge of P_1 repels electrons in P_2 which flow down the wire to the positive (+) pole of the battery. As electrons accumulate in P_1 and leave P_2, P_1 begins to repel incoming electrons and P_2 attracts outgoing electrons. Soon, these forces exactly equal the electrical

A CAPACITOR



Metal (Conducting) Plates
"A"
Insulator
Wires
"B"
P_2
P_1
Battery
+
Path of electrons

pressure of the battery and no current flows. The capacitor is now charged.

Suppose we remove the battery from the circuit and connect the capacitor's wires together ("C" below). Electrons from P_1 flow into the wire and into P_2. Soon P_1 runs out of excess electrons, and P_2 receives enough electrons to fill its electron shortage, and current stops flowing.

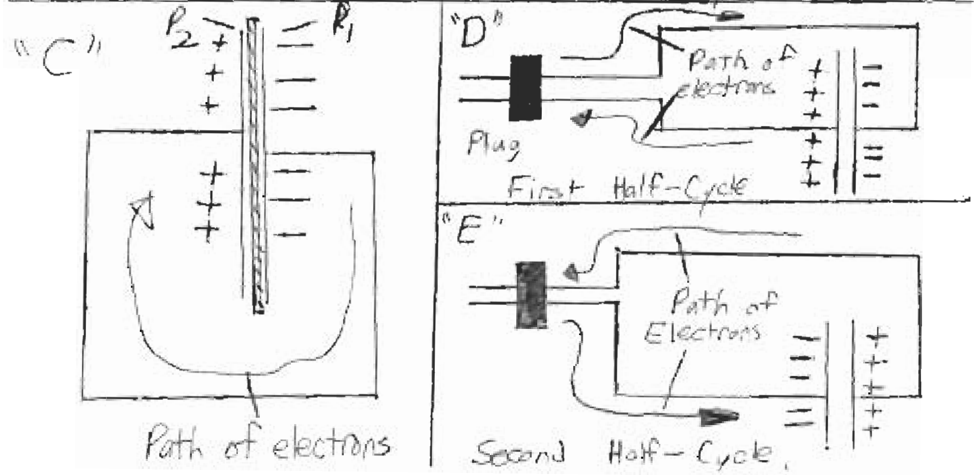
We have seen that a capacitor does not conduct DC (current that flows in one direction). Can a capacitor conduct AC? (Current that switches direction periodically). When the AC voltage is pushing, current begins to flow, charging the capacitor ("D" above). Before the capacitor is completely charged, the voltage reverses, pushing current through in the other direction ("E" above), charging the capacitor in the opposite direction. We can see that a capacitor does conduct AC. The capacitor is an important part of radios. Capacitance is measured in microfarads.

The resistor is another important part of radios. The symbol for a resistor is listed in the symbols index on the display board. In following figures I will refer to resistors with this symbol.

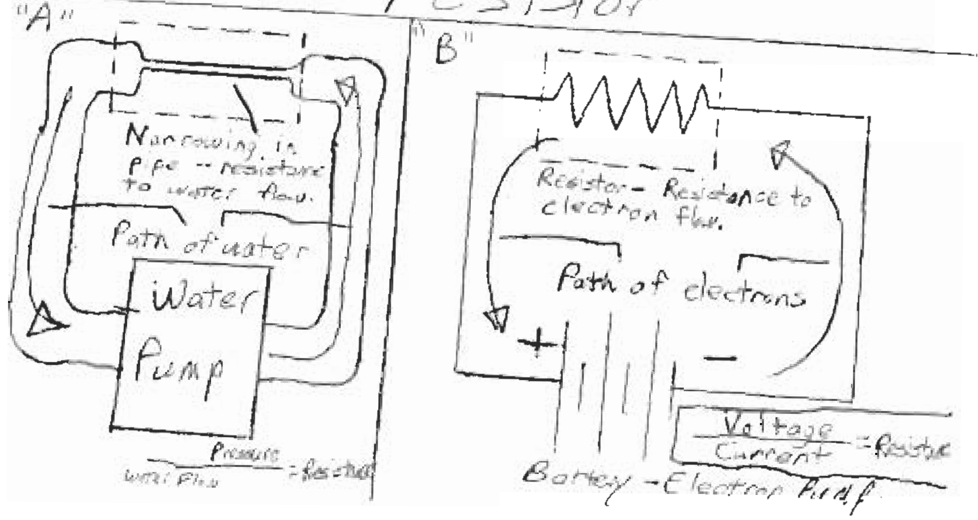
It is easy to explain resistors and their properties by thinking of an electric current as water running through piping. Voltage is the pressure behind the water, and current or amperage is the amount of water. A resistor in our water pipe model will be a narrowing in the pipe. An electrical resistor is usually made of carbon or thin wire, but we will use its symbol.

"A" above is a drawing of a resistance and a water pump. The water pump is supplying a certain amount of water pressure. This

Characteristics of the Capacitor



The resistor



pressure is pushing a certain amount of water through the pipe system (per time unit). It seems reasonable that if we double the water pressure, the amount of water flowing through the system will also double (per time unit). It seems reasonable that the ratio pressure/amount of water flow will always remain the same, provided the resistance remains the same.

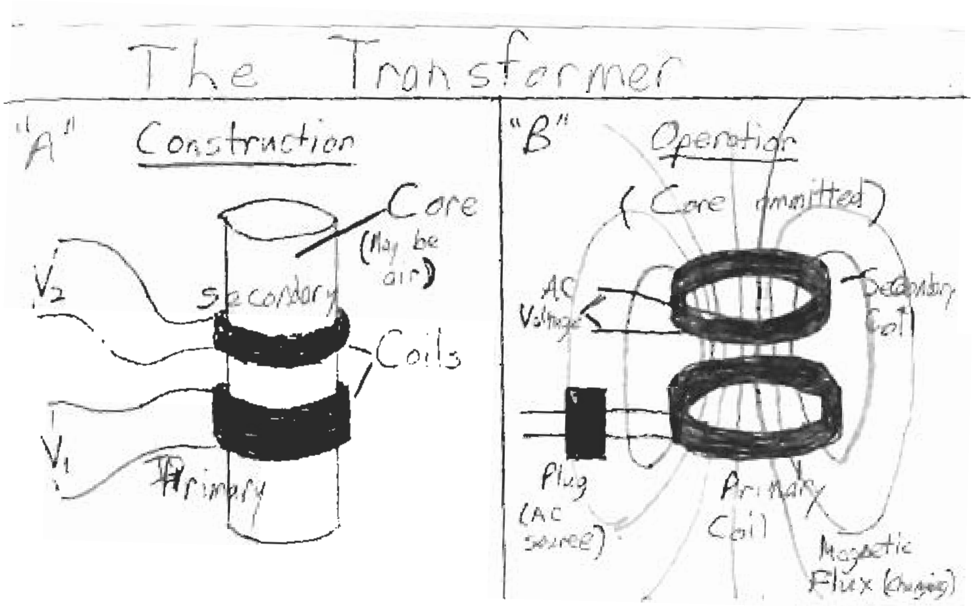
In "B" pipes are replaced by wire, water is replaced by electrons, a narrow pipe is replaced by a resistor, and the water pump is replaced by a battery. But the characteristics are the same.

Voltage (pressure)/Current (amount of electrons flowing) remains the same. Resistance has been defined as Volts/Amperes and is measured in ohms.

Another very important part used in this radio is the transformer. Its symbol is shown in the symbol index. You will notice there are two kinds of transformers. A transformer is two coils of wire wound around a core (see "A" below).

If an alternating voltage V_1 is applied across the wires of one coil, another alternating voltage V_2 appears across the wires of the second coil. The coil to which voltage is applied is called the primary coil. The other coil is called the secondary coil.

In figure "B", AC is run through the primary coil. This makes the primary coil an electromagnet which is changing polarity periodically. The changing magnetic field induces an AC voltage in the secondary coil. (I will not attempt to explain why). The symbol for the transformer is listed in the symbols index on the display board. The ratio of turns in the symbol represents the ratio of turns in the actual transformer.


The Transformer
"A" Construction
Core
(May be air)
V_2
Secondary
Coils
V_1
Primary
"B" Operation
(Core ommitted)
AC Voltage
Secondary Coil
Plug (AC source)
Primary Coil
Magnetic Flux

"C" below is a transformer with twice as many turns in the primary coil as in the secondary coil. The voltage across the primary coil is twice that of the secondary coil, and the current of the primary is half that of the secondary.

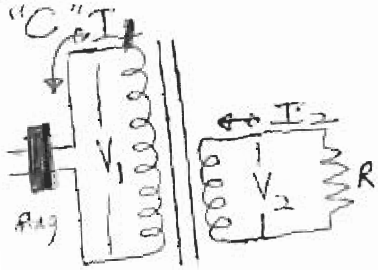
"D" below is a transformer with twice as many turns in the secondary coil as in the primary coil. The voltage of the primary coil is half that of the secondary coil, the current of the primary coil is twice that of the secondary. Transformers are used to change voltage/current ratios in AC and to couple two circuits together so that DC cannot flow between them.

Probably the most important circuit in radio work is the parallel resonant circuit. It consists only of two parts: a coil and a capacitor. In figure "B" the coil is part of a transformer. When the switch is opened the magnetic field quickly collapses around the primary coil. This induces a voltage in the secondary coil, which charges the capacitor in one direction("C"). Once the magnetic field in the primary coil is dead the capacitor is free to discharge through the secondary coil. As it does so, it creates another temporary magnetic field in the transformer. Soon the capacitor is discharged, and current flowing through the secondary coil drops to zero. But now the magnetic field set up earlier by the secondary coil begins to collapse. This induces a voltage and charges the capacitor in the opposite polarity from the original charge ("D"). This new charge also begins to discharge through the coil. In doing so, it sets up a magnetic field in the coil, ..., and the capacitor is charged in the original direction("C"), and we are back where we started.

This swinging back and forth should continue forever, but there are

Transformers Make Voltage/Current Changes

"C"

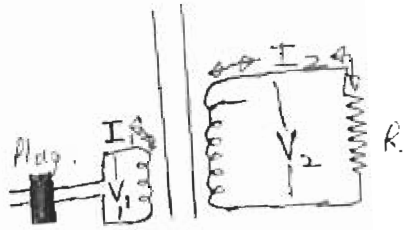


Turn Ratio 2 : 1

Volts (V) 2 : 1

Current (I) 1 : 2

"D"



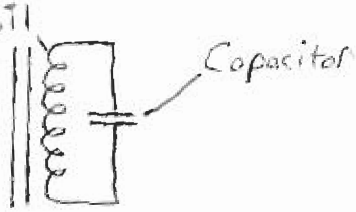
Turn ratio 1 : 2

Volts ratio 1 : 2

Current Ratio 2 : 1

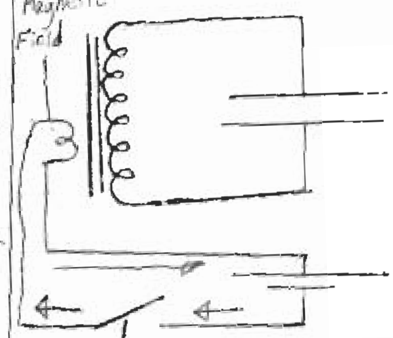
Parallel Resonant Circiut

"A"



A parallel resonant circiut

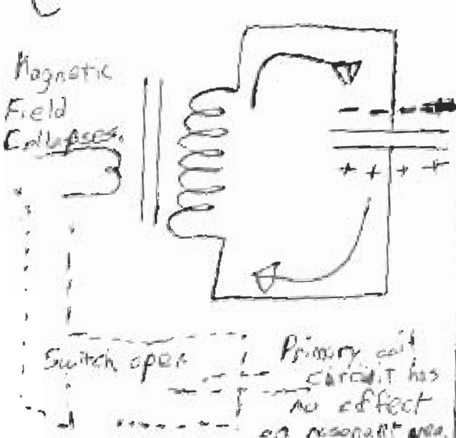
"B"



Switch closed, current

Cont. of "B"

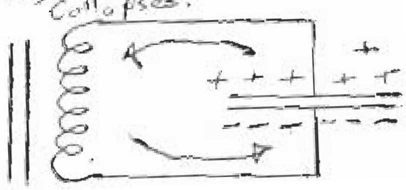
"C"



Cont of "C"

"D"

Second Magnetic Field Collapses.



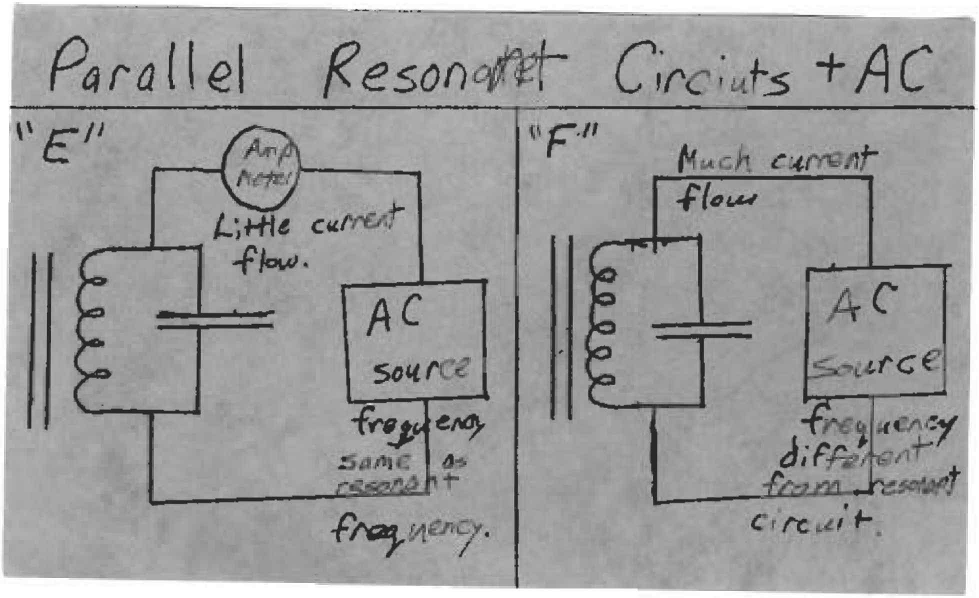
resistances in circuit which slowly weaken the oscillations.

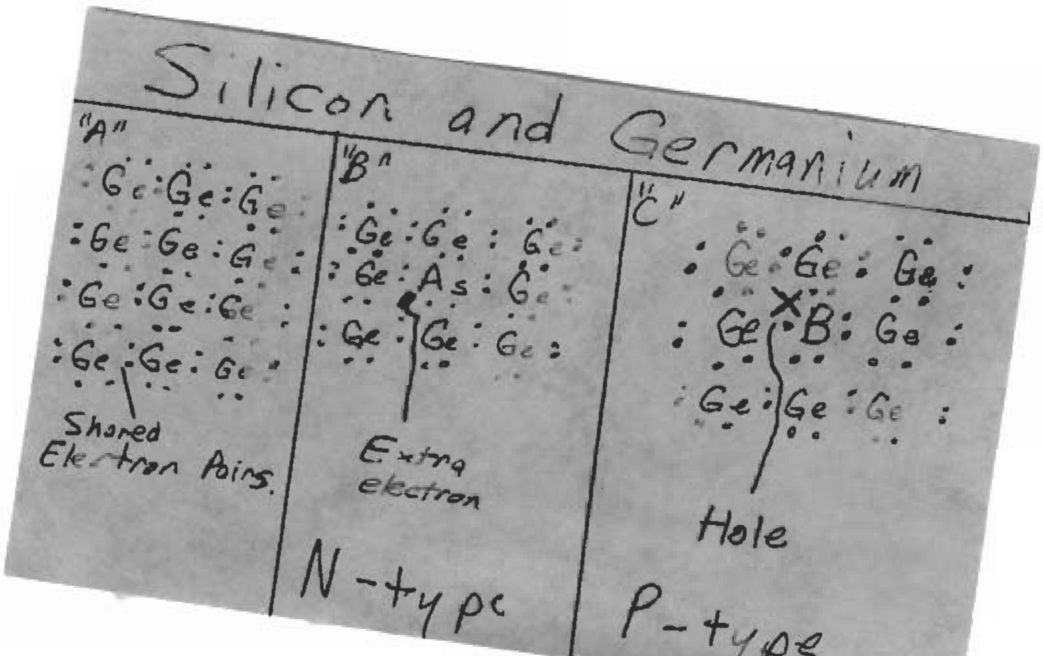
A parallel resonant circuit goes through cycles; the capacitor's charge shifting back and forth. The number of times a resonant circuit does this per second is its frequency. If we apply an AC voltage to a parallel resonant circuit of the same frequency of resonance ("E"), oscillations build up in the resonant circuit. When the AC is turned on, the capacitor charges. Current begins to flow through the coil,...., and soon the capacitor is charged in the opposite direction. By this time the voltage has switched. This increases the charge of the capacitor. After many cycles, the capacitor is always charged with esactly the same voltage and polarity as the AC voltage and all current flow stops.

In "F", AC of a different frequency is applied. Much current flows.

The diode is an important part used in radios. Diodes are made from either germanium or silicon. Germanium and silicon both have four outer electrons. They both form crystals similar to that of a diamond. "A" is a two dimensional representation of a germanium crystal. (Only the outer electrons are shown.) Each germanium atom shares two electrons with each of its neighboring germanium atoms. Because all electrons are tied down, the germanium crystal is non-conducting.

Suppose we add some arsenic to the germanium crystal. Arsenic has five outer electrons, instead of four, but it fits into a germanium crystal anyway ("B"). Because arsenic has five outer electrons instead of four, it has one electron not tied down in covalent bonds. This electron is free to move around the crystal. The crystal conducts electricity because this electron can move about. If we remove this electron the crystal again becomes non-conducting. This is called N-type germanium.


Parallel Resonant Circiuts + AC
"E"
Amp meter
Little current flow.
AC source
frequency same as resonant frequency.
"F"
Much current flow
AC source
frequency different from resonant circuit.


Silicon and Germanium
"A"
Shared Electron Pairs.
"B"
Extra electron
N-type
"C"
Hole
P-type

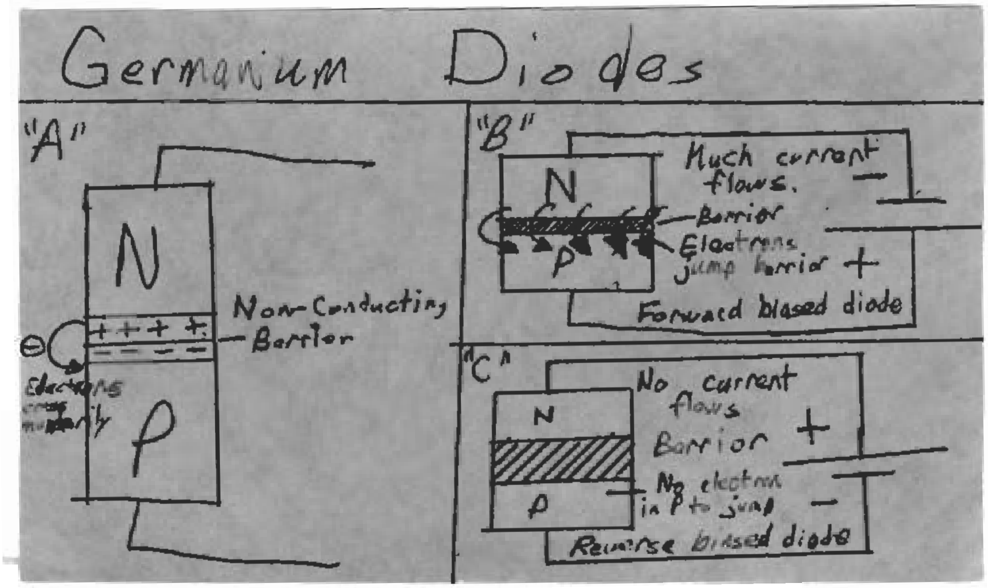
Suppose we add boron, a substance with three outer electrons, to the germanium crystal. The boron blends into the crystal forming complete covalent bonds with three of the surrounding germanium atoms. The fourth germanium atom contributes its electron to the fourth covalent bond, but the boron, having only three electrons, does not ("C"). This "hole" can move around in the crystal. This crystal can conduct electricity, too, but because of moving "holes", not moving electrons. If we add electrons to neutralize the holes, the crystal becomes non-conducting. This is P-type germanium.

A diode is made by joining N-type and P-type germanium (or silicon) and connecting a terminal to each type of material ("A").

When the materials are joined some electrons immediately jump from the N-type to the P-type material, filling in the holes near the boundary, and using up the electrons near the boundary. This makes a very thing non-conducting barrier. Now the material in the barrier on the N side is positively charged, and the material on the P side is negatively charged.

If the diode is forward biased as in "B," much current flows. Electrons from the negative wire of the battery flow down the wire, into the crystal, and then jump the barrier to neutralize a hole. If a diode is reverse biased ("C"), no current flows. The barrier gets much bigger because both holes and electrons flow away from the barrier, leaving non-conducting material. Summing up, a diode conducts in one direction only.

Suppose we run AC through a diode. Because a diode conducts only in one direction, a surging DC will result.



Germanium Diodes
"A"
N
Non-Conducting
Barrier
P
"B"
N
Much current flows.
Barrior
Electrons jump barrior
P
Forward biased diode
"C"
No current flows
N
Barrior
No electrons in P to jump
P
Reverse biased diode

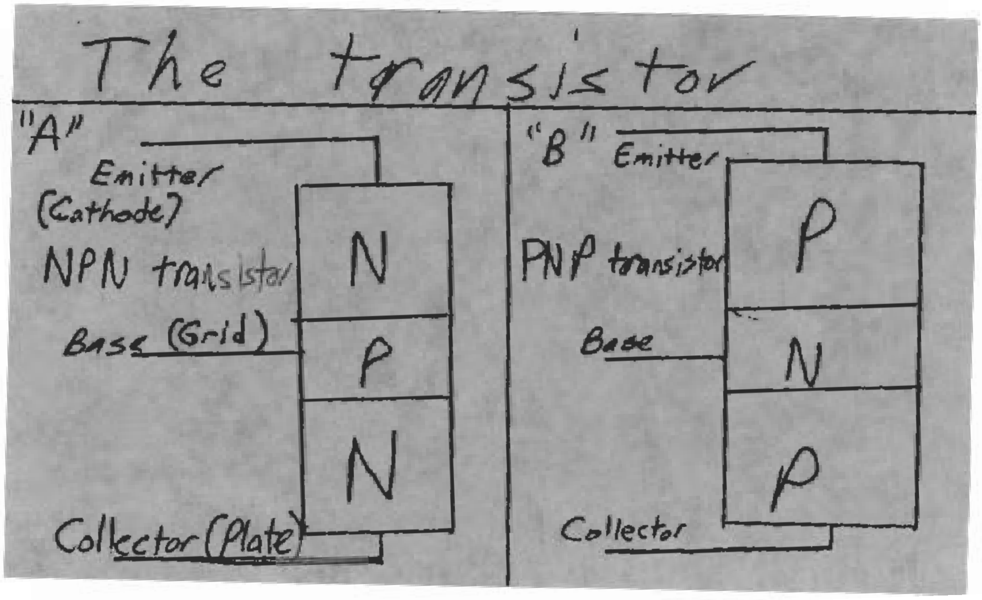
The transistor is the most important part in a modern radio (some radios still use tubes) because transistors are the only part used in modern radios that can make a signal stronger.

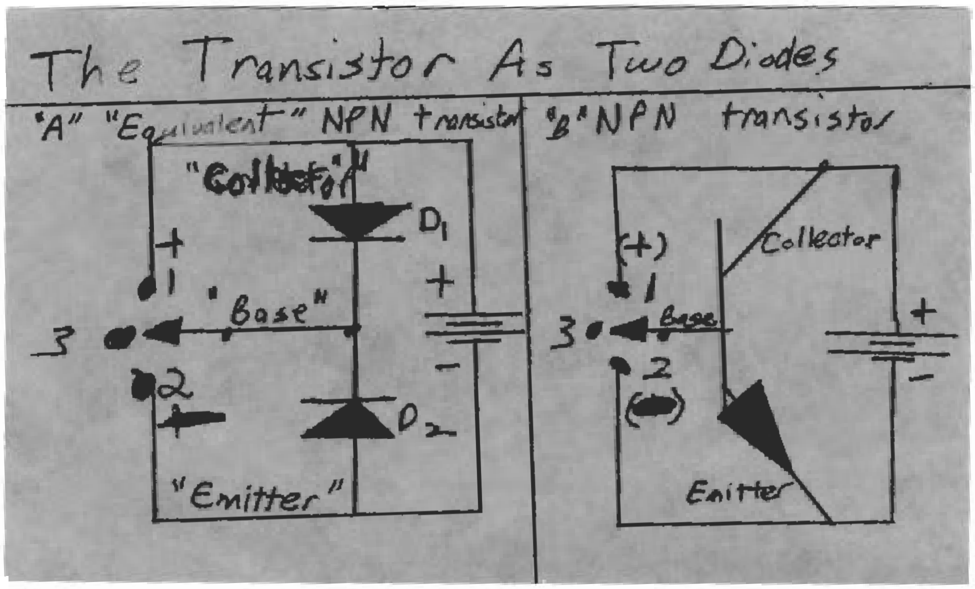
Transistors are made of P and N type germanium (or silicon) but are different from diodes. The two types of transistors used in this radio are the NPN and PNP ("A," "B"). Transistors have three terminals: the emitter, the base, and the collector. For tube fans, the NPN transistor is just like a triode tube, with the emitter as cathode (no heating required), the base as the grid, and the collector as the plate. The PNP transistor is the same as an NPN transistor, except the battery polarity must be switched. Of course transistors are not exactly like tubes. They are just similar.

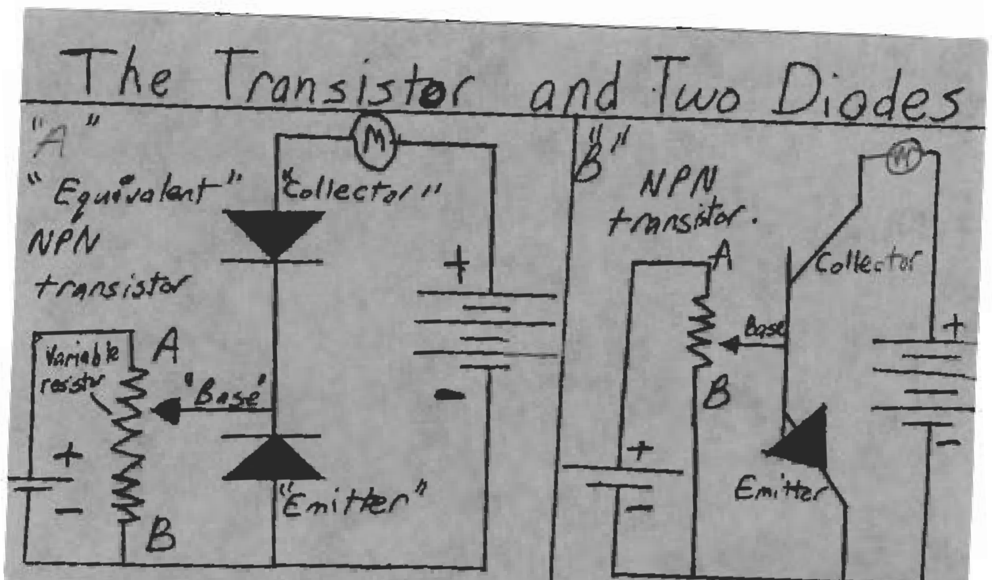
The symbol for the transistor is shwon on the symbols index. The transistor can best be explained by a two diode "equivalent" circuit ("A"). (In these diodes the electron flows WITH the arrow). If the switch is thrown to 1, D_2 is forward biased because the "base" is positive. Much current flows. If the switch is thrown to 2, D_1 is reverse biased and no current flows. If the switch is thrown to 3, no current flows.

In "B" the NPN transistor acts about the same as the two diodes in "A". When the switch is thrown to 1, current flows; but when the switch is thrown to 2 or 3, no current flows. When the base of an NPN transistor is made positive, much current flows. When the base is made negative, no current flows. PNP transistors are exactly the reverse.

In "A" of the next transistor picture there is another two-diode "equivalent" transistor. The voltage across the base and emitter is controlled by a variable resistor. No matter what the variable resistor's setting, no current flows through meter M. This is not the case with a real transistor.


The transistor
"A"
Emitter
(Cathode)
NPN transistor
N
Base (Grid)
P
N
Collector (Plate)
"B"
Emitter
P
PNP transistor
Base
N
P
Collector


The Transistor As Two Diodes
"A" "Equivalent" NPN transistor
"Collector"
D_1
+
1
+
"Base"
3
-
2
D_2
"Emitter"
"B" NPN transistor
Collector
(+)
1
+
3
Base
2
-
(-)
Emitter


The Transistor and Two Diodes
"A"
M
"Equivalent" "Collector"
NPN
transistor
+
Variable resistor
A
"Base"
-
+
-
B
"Emitter"
"B"
NPN
transistor.
M
A
Collector
Base
+
B
+
-
Emitter
-

In "B" the same circuit as "A" is set up except the transistor equivalent is replaced by an actual transistor. We might expect to get the same results. We start with the variable resistor in position B. Sure enough, no current through meter M. We nudge the variable resistor toward A, but the current going through meter M goes way up! It only takes a very small base-emitter voltage to drive the collector current very high.

This is the principle of a transistor: it can make a very small voltage change very large.

An important part of a radio is the mixer. The mixer combines two AC currents. The frequencies that come out of the mixer, not only include the two original frequencies, but also their sum and difference. To explain why, we need a representation of AC. A good way to represent AC is with a wiggly line and straight line "A". One side of the straight line represents negative voltage; the other represents positive voltage. "B" and "C" represent two AC voltages to be mixed. "D" is the resulting voltage that is applied to the mixer. "E" is the output of a diode mixer. It contains all four frequency components. Mixers are used in superheterodyne receivers to change the frequency of an incoming signal and to change AM into audio. A mixer may be a diode or a transistor.

Following the Signal Through the Radio

This is the way a radio should work. The radio signal originates in the loop antenna. It is an alternating voltage of a certain frequency. Its amplitude is changing with the program material. It, and the oscillator signal are sent to the first mixer. Here the signal's frequency is changed to 455 kc. It then goes into the I.F. amplifier, where it is amplified.

Then it reaches the second mixer, and is changed to audio. The audio is amplified and sent out the speaker.

This is not the way it works in this radio. Everything works well until the I.F. amplifier. The I.F. amplifier oscillates at 455 kc., but it does amplify. When the signal gets to the second mixer, it mixes with the oscillation frequency. This produces a squeal unless the two are exactly the same frequency, or the signal is tuned in exactly. This oscillation makes this radio capable of receiving Morse code and single side band transmitions.