

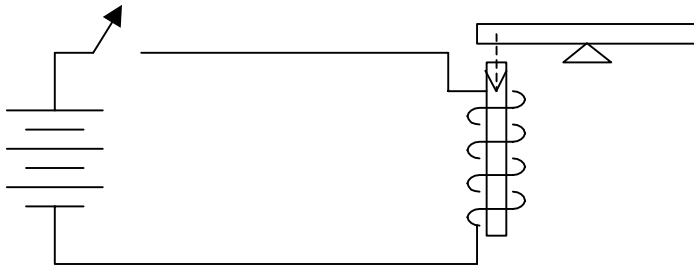
EGR 215 Topics in EE Electronics

Edison was not the first electrical engineer, as many claim. Instead, the honor belongs to Samuel F. B. Morse.

Morse and Actuators

Morse was an American painter and a graduate of Yale. In 1832, travelling from Europe, he overheard other passengers discussing an invention of the electromagnet, had a brainstorm, and came up with the **telegraph**. (Other people had similar ideas as early as 1800.) He built one, patented it by 1835, got funding from Congress for the first telegraph line in 1838, and battled lawsuits from competitors until 1854! This started a worldwide industry.

Morse basically invented the **actuator, a device that changes electricity into motion**. When a switch (which we can think of as the first **sensor, a device that changes a physical property into an electrical signal**) closes at one end, a DC voltage from a battery is applied to the telegraph line, which energizes an electromagnet at the far end. The magnet pulls a steel bar down, causing the typical click. It's really not much more than a glorified physics experiment, an application of electromagnetics. Morse's system is of course digital. It does not matter how big the current the switch



controls is as long as it is big enough to move the bar on the clicker.

A wide variety of actuators exist today to turn electric signals into various sorts of motions, such as relays (the first implementers of digital logic), motors, speakers, etc.

In addition to the physical apparatus, Morse invented the Morse code, the first digital encoding of numbers and letters. It was based on human ability to interpret sounds rather than on binary arithmetic, so different codes (ASCII) are used to represent numbers and letters in computers, although the basic idea of using a sequence of 1's and 0's (shorts and longs) is the same.

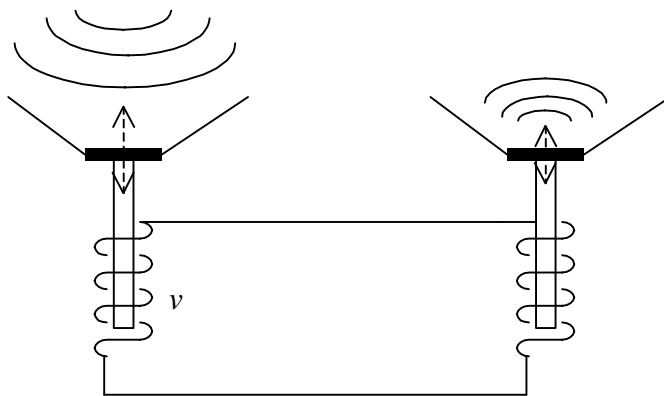
Bell and Transducers, Edison and Amplification

Alexander Graham Bell was a Scotsman educated in Edinburgh and London, and a college dropout due to lack of funds, who moved to the US. His lifelong interest was

work with the deaf. In 1872 he tried to make a device to make sound visible for deaf people. A theorist, he worked with Thomas Watson, who did the technical work, (A common partnership - engineer and technician - in electrical engineering today.)

Bell first had to turn sound into electricity. He developed the first **transducer, an object that translates physical phenomena (sound, motion, position, temperature, moisture, weight, etc.) into electrical signals and back again. A transducer is both sensor and actuator.** Shouting into a diaphragm caused it to vibrate. Attaching it to a magnet moved the magnet in a coil, generating a voltage (by Faraday's Law). This was the first microphone. Bell next had to invent a way to turn electricity into something you could see. He used the electromagnet concept from the telegraph, attaching a metal disk to a diaphragm. The electromagnet connected to the microphone varied, which varied the pull on the disk, which moved the diaphragm. Unfortunately, the diaphragm moved too fast to see - but you could hear it make a noise! It was a speaker, and the combination was the telephone.

Bell found that he really only needed two of the same thing. The microphone would work in reverse, converting electricity into sound about as well as the speaker. Thus, he had a **transducer**. The basic approach is still used in sound-powered phones found on shipboard and in other high-reliability applications.

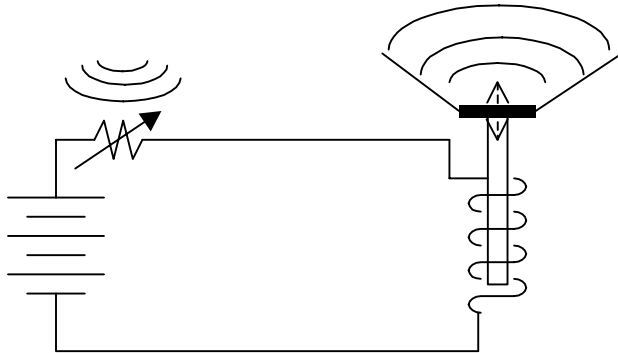


Patented 1876, the first lawsuit was in 1877, plus 100's more lawsuits followed, the most complex patent litigation in history--lasted throughout the life of the patent. Bell went back to working with the deaf when he was not meeting with patent lawyers.

Because the voltage was generated by the energy in a human voice, it was quite small, and the sound produced at the other end was faint. Electricity could travel over wires much further than one could shout through the air, so it was a success, but you still had to shout into the telephone, which made conversation difficult.

Thomas Alva Edison, who had hearing loss himself and probably could not hear voices on the telephone very well, felt a need to make the delivered voice louder. He developed a new kind of sensor, a container of compacted carbon powder that changed resistance as a membrane on one side moved in and out with the vibrations of sound. This is the

carbon button microphone, still in use. Note how battery power can **amplify** the energy of the sound producing the change in resistance.



The telephone is an **analog**, not digital device. **Analog (continuously variable) voltages** and currents, at frequencies in the 20 Hz-10,000 Hz range can be used to produce sound. This is far faster than any mechanical switch.

Marconi and the Filter

Marconi was an Italian. He used a Morse key and a spark gap to transmit electromagnetic waves (radio). Finding no interest in Italy he moved to England and filed his first patent in 1896. By 1899 he was transmitting Morse Code over 100 mile ranges. In 1900 he filed a patent in the US for a system that allowed different stations to operate simultaneously by using different frequencies. **It used capacitors and inductors to filter out the unwanted frequencies.** The patent was overturned by the US Supreme Court in 1943, which held that it was based on prior work by Lodge, Telsa and Stone.

The filter in all its various forms is still with us.

Edison and the Vacuum Tube

In 1881, a year after the invention of the light bulb, a technician named Hammer noticed a blue glow around the positive filament in an experimental light bulb - but only in a dark room! Edison patented it in 1883 and it became known as the Edison effect. It was a curiosity until 1897 when an English scientist showed that the glow was due to electrons, and another, J. Fleming, developed the **diode**, a tube with two electrodes. Electrons could move in only one direction, creating a **one-way valve for electricity**. At the time its principle use was in detection of radio waves.

In 1907 Lee de Forest, an American, invented the **triode**. He put a grid between the two electrodes. By varying the voltage on the grid, the number of electrons flowing between the anode and cathode could be changed. A small change in voltage created a large change in current flow - **a voltage controlled current source!**- and the first universal

amplifier, able to make small signals large. The problem was stability - the gain kept changing wildly so signals were loud one second and silent the next.

Vacuum tubes had a long career in electronics, including radar and the first digital computer, before being overtaken by the transistor in the 1950's. Now they are found only in very high power, high frequency applications like radio transmitters, in TV sets as a display technology, and in some audiophile amplifiers.

Armstrong and Negative Feedback

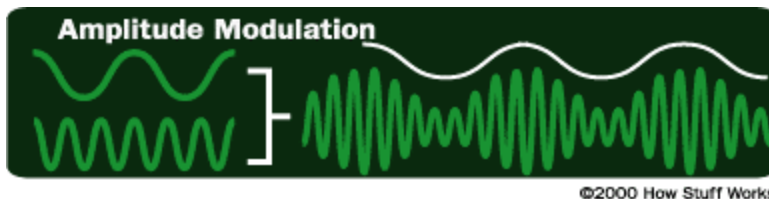
Edwin Armstrong was a classic geek who was happiest alone in an attic full of electronics gear. He went to Columbia University. In 1912, as a junior, he invented the **negative feedback circuit**, which made the triode a stable amplifier with a gain of around 1000. It was the basis of AM radio reception, loud enough for the family to hear. When Armstrong pushed the gain up, the circuit oscillated at a specific frequency - and he could use it as a transmitter. The transmitter technology is still used today.

De Forest challenged Armstrong's patent, and the case took 14 years to clear.

Armstrong later invented the superhetrodyne circuit, an advanced filter/amplifier that is the basis for 98% of radio and radar receivers today.

In the meantime, Armstrong founded RCA with a business partner, Sarnoff, who basically pushed Armstrong out of management. Perhaps to get back at Sarnoff and RCA, in 1933 Armstrong basically invented **Frequency Modulation (FM)**.

In AM, the loudness of your voice is superimposed on the magnitude of (much higher frequency) radio waves.



In FM, the loudness causes frequency to vary while the magnitude is constant. It's a lot less noisy.

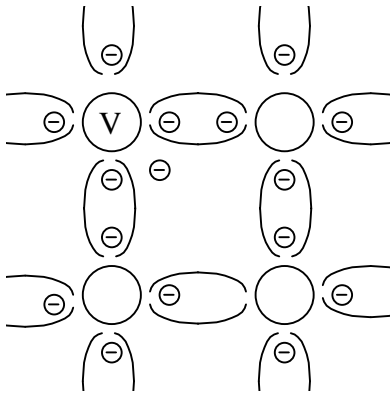


Bardeen, Brattain, Shockley and the Transistor

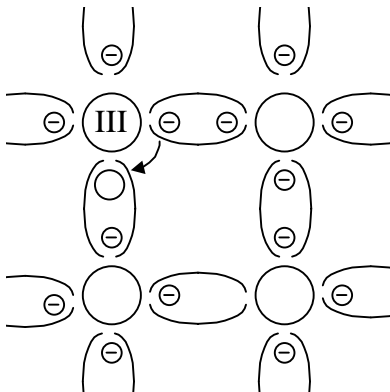
Post WWII, a supervisor in Bell Labs put together a team of solid-state physicists to invent a **solid state** amplifier. Shockley was the theoretician in the team, Bardeen the experimentalist and Brattain the lab person. The team worked well together until, in 1947, Bardeen more or less invented the first transistor while Shockley was on vacation. Horrified, Shockley rushed back, ensured he was in the centerpiece of the picture of the inventors, and then invented a significantly improved version on his own. Bardeen took it pretty well, but Shockley was pushed out of Bell Labs.

He moved back to his Mom's house in California and started Shockley semiconductors. Silicon Valley is where it is because of Shockley's Mom's house. He attracted a lot of young talent to his company but he was such a lousy manager that the first bunch left en masse and founded Fairchild, which invented the integrated circuit. This process of division has been going on in the Valley ever since. Shockley eventually went out of business and had to be a professor because he couldn't work with anyone.

The transistor depends on having a **semiconducting** material, usually silicon, which forms a lattice with its electrons in covalent bonds. Then **impurities are added to create either an excess of electrons (n type material) or a deficit (p type)**. Conduction electrons and holes (a spot in an atom that is missing an electron which can move) are called **charge carriers** because they can move charge.

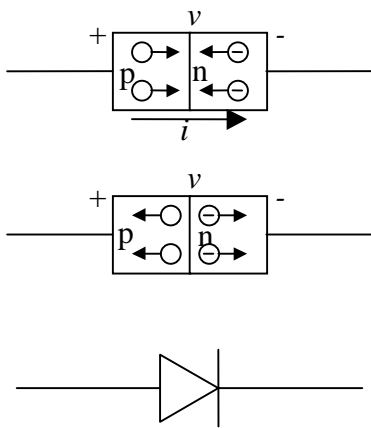


The first picture shows four atoms in the lattice with covalent bonds and electrons in the bonds. The electrons in the bonds are not available for conduction, so pure silicon or germanium is not a good conductor. However, if a Group V atom (one with five electrons, not four in the outer shell) is added to the lattice (marked V in the picture), its extra electron is not in a covalent bond and is available to conduct. There are fewer of these conduction electrons than in a metal, but usually enough to be considered a good conductor. This is n type material.



If on the other hand a Group III atom is added, one of its covalent bonds will not have an electron. The deficit, or lack of an electron in a covalent bond, is called a **hole**. The **holes also move**, as electrons in bonds switch from atom to atom in the lattice. The drawing shows an electron moving to the left to fill the hole. The electron leaves a hole behind, so in effect the hole has moved to the right. This is p type material.

If you put p and n type material together at a **junction**, the electrons move towards the holes to fill them at the boundary - creating one way current flow, like the diode tube. **Thus, one pn junction is a solid state diode.**

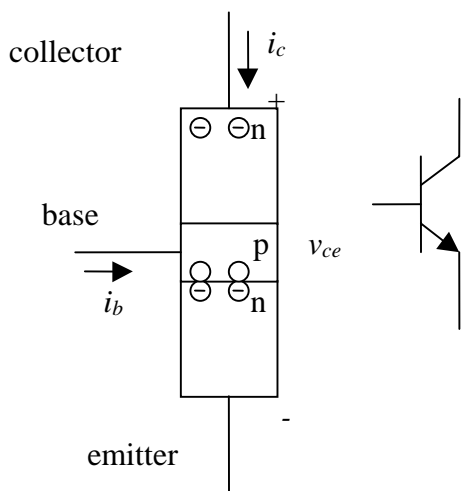


In the top drawing, the diode is forward biased by the direction of the applied voltage. The voltage causes holes and electrons to move as shown. **At the junction they combine**, resulting in an effective current i .

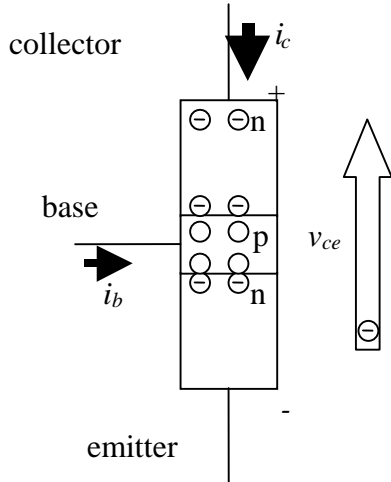
In the second picture, the voltage polarity is reversed. Holes and electrons move away from the junction, clearing the junction of charge carriers and resulting in no (or, small) current flow.

The third picture is a diode circuit symbol.

Put two junctions back to back, and nothing happens unless you inject some electrons into the p material, turning it into n material and allowing current flow. Thus, **relatively large currents can be controlled by relatively small currents -- a current controlled current source, or amplifier.**



Here, the base current is zero. Holes in the p region move to the lower pn junction under the influence of the bias voltage v_{ce} . Since there are no holes near the upper pn junction, and no electrons, therefore there is an absence of charge carriers, and no current flows from collector to emitter. On the left above is the circuit symbol for an npn transistor.



In the next drawing, the base current is non-zero. This removes electrons from the p region, creating extra holes. The extra charge carriers transport electrons across the upper pn junction, creating a net electron flow from the bottom to top, or current from top to bottom. The number of electrons moved is far greater than the number of holes injected.

(This charge carrier explanation is pretty simplistic, but a good starting model for the transistor.)

Compared to tubes, transistors are low power, cheap, and tiny. They remain at the core of electronics.

Electronics is the study of electronic devices, especially semiconductors, and of transducers and some actuators, and the circuits in which they operate. Analog electronics deals with continuous values, while digital electronics deals with values that are either off or on. More on digital later.