A Brief History of Your New Radio

The little radio you hold in your hand is the result of thousands of people's work and ideas. There are a lot of "histories" that could be written about it, here's one of them. I hope you enjoy it.

First, we learned about radio…

In 1887, Heinrich Rudolf Hertz (1857-1894), a German physicist, performed an experiment to test the predictions of two other scientists, James Clerk Maxwell (1831-1879) from Scotland and Michael Faraday (1791-1867) from England the electromagnetic waves should be able to travel through space, and not just through wires.

His experiment was a success, and he was able to show that you could send "radio waves", as they later came to be known, through empty space. At the time it was really only interesting to scientists, no one expected to actually do anything with it.

Then, we figured out a use for it...

Pretty quickly, though, people started to see that you could do something with radio waves. In particular, you could use them to send information. At the time, the way you sent messages great distances was using the telegraph, developed commercially by Samuel Finley Breese Morse (1791-1872), an American. Telegraphy used long wires stretched between cities and depended on "morse code" (actually invented by his assistant, Alfred Lewis Vail (1807-1859) , which is a way to spell with long and short pulses.

Usually, those pulses were the result of a "code key", a kind of switch which caused an electromagnet on the other end go the wire to attract an arm on a device called a "sounder" which makes a click. The operator learns to understand the meaning of the clicks, and can "copy" the code. The telegraph was used to report on the battles of the American Civil War, and changed the way people got news and information, but it was very limited.

About the same time, many people began thinking about "wireless telegraphy". (In fact, while we refer to "radio", the name "wireless", shortened from "wireless" telegraphy is used to talk about the technology, though "radio" is still what we call the stuff we actually listen to.)

The idea of not needing wires to send telegraphic messages was very attractive to businessmen. Scientists are happy with experiments but "inventors" usually want to sell things; and "wireless" looked like it could make someone a lot of money!

Then, we found a way to sell it…

So, right around the turn of the twentieth century, a lot of people were trying to figure out how to make Hertz waves useful and "wireless" possible. People like Nikola Tesla (b. 1856, d. 1943), a brilliant Serbian-born American inventor. Tesla was one of the first practical experimenters in wireless, but, tragically, in spite of his amazing insights and abilities, he died poor and alone, in a hotel room. His life was very interesting, and worth reading about.

Even right here in South Bend in 1899, an Electrical Engineering professor at Notre Dame named Jerome Green made what may be the first long distance radio transmission in the United States. "Long distance" is relative, and his transmission was from the Notre Dame campus to the

Saint Mary's campus, about two miles. He used a very long antenna hung from the side of the basilica, and managed to send the morse code for the letter "S", which is three dots. His attempts to repeat his experiment in Chicago failed, and he blamed the mass of overhead wires used for telephone and telegraph for interfering with the signal. Today, there is an Amateur Radio station called "the Jerome Green Amateur Radio Station (JGARS) which uses the call sign "ND1U" It is part of the College of Engineering. Amateur Radio operators (called "hams") use radios for experimentation, public service, and fun. Becoming a ham is very easy with a little study, and it's a great hobby.

Another inventor early on in radio was Guglielmo Marconi (1874-1937). Marconi was not the brilliant inventor that Tesla was, but he was a far better businessman. Marconi is sometimes considered "the inventor of radio", but this is misleading. He commercialized radio, that is, he found a way to sell it. His experiments and inventions were not necessarily as clever as others, but because he managed to get something built he could sell before others, he was successful. His product was wireless telegraphy, and once he managed to sell his version to the U.S. Navy, he was sure to be a commercial success. But, even with this commercial success, wireless was still just telegraphy, and expensive, and only used when you really needed it (in particular, by ships at sea, where wires just won't do). Then, we made it talk…

By this time, the telephone was also in regular use, having appeared as a device for local use (it couldn't compete yet with the distance that the telegraph could manage). But it didn't take much to imagine "wireless telephony" as the next step. Making it work, though, was another matter. One of the very little known inventor-heroes of radio is a man named Jozef Murgaš (1864-1929). He was a Slovak, and a Catholic Priest who came to America and lived in Wilkes-Barre Pennsylvania. He was also a prolific and brilliant inventor, particularly of radio devices. His story is something like Tesla's because he wasn't a very good businessman and so he gets little credit for his work, but, unlike Tesla, his end was not tragic. He was happy with what he accomplished, even if he never became famous.

Father Murgaš started with wireless early on, and right away he invented a twotone system of telegraphy far more effective than the morse code. This system allowed people who knew it to transmit text about five times faster than the morse code used by Marconi's system. Even though it was far better, Marconi had locked in his system by selling it to the U.S. Navy who wasn't willing to throw away the equipment they'd spent so much on. So, outside local enthusiasts, Murgaš' system was never adopted.

Murgaš may also have been the first in the United States to make a voice transmission. He holds U.S. Patent 1,196,969 on a device that helped make this possible. While he never managed to successfully sell his work, it didn't bother him, he was happy with his life. However, others were watching him very carefully because they saw something they could use to make themselves rich (and famous, which, it turns out, is just as important to that sort of person). Thomas Alva Edison (1847-1931) was one of those people. You might know Edison as "the inventor of the light bulb". This isn't quite right. Once again, like Marconi, Edison was a commercializer. Edison was a prolific inventor in his own right, and he is worth reading about. But the main part of his genius was recognizing and selling good ideas. Edison watched Murgaš carefully, and even spoke with Marconi about what he was up to. Murgaš may not get the credit, but he was a very

important inspiration to other inventors who eventually managed to sell his ideas in various forms, and so get both the credit and the money. But, all of efforts to make radio "talk" were hampered by a big problem: tiny signals. To make wireless telephony useful, some way to was needed distinguish between "signal" (the information, in this case human speech) and "noise" (all of the "non-information" which came from many sources, natural and man-made, remember Professor Green's trouble in Chicago).

Different things were tried, which mostly involved "tuning" the "wireless set" (receiver) better. Making it listen to a smaller portion of the electromagnetic spectrum was the first problem that was tackled. The knob on your radio that allows you to "choose a station" is all about that. It moves a little "window of listening" up and down the band, and the stations each have their spot. This was a very new idea back then, and much more crude, but it helped. It wasn't enough, though, to really make things work well. Somehow, the signal had to be "amplified", that is, made stronger so it could be heard. Then, we found that the light bulb had a secret…

Edison's method of invention was what we would call today, "brute force" (or, if you want to be all scientific about it, "empirical"). When he was commercializing the light bulb, (it had already been "invented", he was trying to make one he could sell), he made hundreds of different versions using all sorts of materials for the "filament" (the glowing part). He tried everything from burnt string to, eventually, tungsten metal which is what he settled on, and what "incandescent" lamps use today (they may be gone in your lifetime as new technologies like CFL (Compact Fluorescent), LED (Light-Emitting Diode), and even more exotic, efficient technologies replace them).

Somewhere along the way, for reasons that aren't clear, he included a piece of wire in the bulb above the glowing filament and sticking out of the top. When he touched it, accidentally he got a shock. This surprised him since the wire wasn't touching the filament. Edison kept meticulous notes, so he wrote it down. It didn't mean anything to him, though, so he also forgot about it. Lee de Forest (1873-1961) noticed it, though. De Forest was an American inventor, something like Edison, in that he was an empiricist. He managed to make useful things without really understanding them well. He wasn't brilliant, like Tesla, but he was persistent, and very interested in personal and commercial success. De Forest realized the there was electrical current flowing from the filament to the wire (in what is called a "thermionic stream"). If a smaller voltage (like the weak radio signal that was a voice) could somehow control that flow, to would be possible to "amplify" it. The small signal could be used to make a bigger copy of itself.

De Forest invented what he called the "Audion" which was just this sort of amplifier. By putting a "grid" between the filament and the wire, he could put a small signal on the grid and influence the flow from the filament to the wire. This was a huge advance, even if he didn't really understand how it worked, other people figured out how to use it. In particular, the telephone companies found it very useful because, remember, they couldn't make phone calls go very far, and "repeaters" that amplified the signal made Long Distance possible. De Forest got quite rich from this, but, he still didn't understand his own work.

On the other hand, Edwin Howard Armstrong (b.1890, d. 1954) did understand it. He was a truly brilliant American electrical engineer who saw the real power of the Audion (technically called a

"triode" because it has three elements). His deep insights into the operation of the triode allowed him to develop something called the "regenerative receiver", which made broadcast radio (the kind you like) practical.

He also invented FM (Frequency Modulation) which is far more pleasant for broadcasts than the AM (Amplitude Modulation) that was used until then. We still use it today, but for talk radio where "fidelity" isn't important, while FM is used for music because it is quieter and can reproduce a wider range of sounds.

Armstrong got into a legal fight with de Forest over the patent on this new circuit. Unfortunately, Armstrong was an ideologue, that is, he believed that if something was "right" he should fight for it to the end. So, instead of making a deal with de Forest, which would have still allowed him to profit from his invention, he felt he needed to "win". He fought de Forest (who had a lot of money to spend and an even bigger idea of how important he was) in the courts, and eventually, he lost the case on a technicality. It was devastating to Armstrong, who lost his marriage, and eventually his life over it. A great tragedy which once again showed how the commercially successful can keep the truly brilliant from contributing.

While Armstrong's life reads like a tragedy, ending in his dramatic suicide, it is a fascinating one, and one of the more fascinating events concerns his wife, Marion McInnis (1898- 1979). Though they had split up when Armstrong became so unstable because of the stress of the lawsuits, and hit her with a fireplace poker. After his death, she pursued and won every one of the suits for her husband even though they only a matter of "moral" victory. A more pleasant connection to your radio is that Armstrong made the first portable radio as a gift for McInnis when they were married.

Armstrong's work revolutionized radio and made commercial broadcasting possible. The creation of the first radio "networks" and the rise of RCA (Radio Corporation of America) is another fascinating story (in which Armstrong figures). But I will leave you to find out about it if you are interested since it is yet-anotherhistory's worth of information. (That's worth learning about!)

From the time that Armstrong's wonderful circuit made radios a practical household item developments in vacuum tubes (the British called them "valves", because the controlled the flow of electrons) developed steadily. Tubes became more powerful and smaller. The advent of World War II brought even more capable and much smaller tubes (called "acorn tubes" because that's what they looked like); but the war also brought something else, something directly connected to your little radio.

Then, we got rid of the tubes…

Of course, even the tiniest "acorn" tubes were much bigger than could fit in your radio. And, not only were they big, they were hot. The filaments in them had been carefully designed to produce more electrons than photons (light waves/particles), which is, of course the idea of a light bulb. But they still had to get hot enough to glow, because it was the heat (therm- from thermionic) that produced the electron stream (-ionic). Heat means power, too. So the batteries that ran portable radios had to be very big, and the voltages required were very high. Your radio runs

from 3 volts, these required 45 volts, and even that had to be converted even higher.

So, tubes weren't very practical for something really portable, and they were inefficient, since a lot of the power needed to run them went into heat. They also didn't last all that long; they burned out just like lightbulbs.

So, what to do about it? Well, in 1905, long before World War II, Albert Einstein (1879-1955) had his "Annus Mirabilis" which means "miracle year" in Latin. It's called that because he wrote four scientific papers which were so far-reaching it took hundreds of scientists decades of work to really understand all the implications of them. Part of the focus was on something called the "photoelectric effect".

This was an observation that when light fell on certain combinations of metals, electricity was produced. This effect was very confusing to scientists because they had concluded that light (which is electromagnetic radiation, just like radio only vibrating a lot faster) travels as waves. Just how waves could do this was quite a mystery. Einstein solved it, but it was very upsetting to the scientists of his time. His solution was to say that light was both waves and particles at the same time. This didn't go over very well because it seemed crazy; but the more it was looked at, the more clear it was that he was right!

These papers began the investigation into Quantum Mechanics, the study of things so small that they are smaller than particles of light itself. You can't see things that are at the quantum level, and they act in very strange ways indeed. In fact, they act so strangely that a prominent scientist declared, "if Einstein is right, science itself is impossible!" Thankfully, he was wrong about that. Einstein was right, and scientists worked it out.

By the time World War II was nearing its end, the people at a really amazing place called Bell Labs, which was the research part of the AT&T's Bell System telephone monopoly, had been working on a project for replacing vacuum tubes in those "repeaters" that first made the Audion tube a commercial success. They needed something more reliable, and lower power. Some of their repeaters were built into the transoceanic cables that ran across the atlantic from America to Europe. Changing a bad tube in a place like that is just a little inconvenient, and powering them meant everything got hotter than they'd like.

So, they were investigating something called "semiconductors". These were materials that were neither conductors nor insulators, but seemed to do some of both.

Conductors allow electric current to flow easily. Most metals are excellent conductors, copper is usually used in wire because it is both a good conductor and not too expensive. It's not cheap either, but it's practical to use. Silver is a better conductor but it costs too much. It is used in special cases, like certain connectors.

Insulators are don't allow electric current to pass; things like rubber, dry wood, and glass are examples. Today, most insulators are man-made materials. Different plastics are very good insulators for low voltages. But if you look up on the poles that carry the power to houses and businesses you will still see glass (and ceramic) insulators for the very high voltages that are

used. (In your neighborhood, before the power gets to your house, it is probably around 15,000 volts, but the receptacles on the walls are only about 1/100 of that, at 120 volts.) Semiconductors, though, are able to conduct sometimes. The first devices made were "diodes" (remember, the Audion was a "triode"). Di- in diode means two. The -ode part is each of the parts (an anode and a cathode). The diode is like a "check valve" used to keep water from backing up in drains, it lets current flow one way, but not the other. The diode is a very useful component, but the real goal was a semiconductor triode, that could act like the tubes and be an amplifier.

Julius Edgar Lilienfeld (1882-1963), who was an Austro-Hungarian born American physicist, received a patent on something he called "Amplifier for electric currents" in 1928. In theory this was what the people at Bell Labs was looking for, a semiconductor triode. In practice, it didn't work. The idea was right, but it couldn't be made. Still, he'd anticipated the work of the team that did make the practical version but more than 20 years.

John Bardeen (1908-1991) and Walter Brattain (1902-1987) were physicists who worked at Bell Labs' Solid State Physics Group under the supervision of William Shockley (1910-1989). Shockley was a brilliant theoretician, but he was also a very greedy man. He wanted fame and fortune, and believed he deserved it. From November to December 1947, Bardeen and Brattain performed practical experiments on the semiconductors in a successful effort to create a working semiconductor amplifier. Shockley, meanwhile, was working on something much more like Lilienfeld's amplifier, all on paper.

Bardeen and Brattain had come to their experiments by a fortunate accident, as is often the case in invention. The materials that were needed for this work had to be very pure. In fact, purifying them was one of the biggest challenges. One of the scientists had gotten a sample of germanium, an early material used in semiconductor production for some tests. He'd connected it to a voltmeter for other reasons, but noticed that if he shined a light on the sample, it produced a very large (relatively speaking) voltage. This was Einstein's photoelectric effect in action, but a much stronger one than they had ever seen.

When they looked careful at the sample, they noticed an irregularity in the middle of it. It seemed to have cooled funny. Probing around, they found that the funny bit in the middle was a little less pure than the ends, forming a "junction" between the two. This was a huge breakthrough. They realized they needed a sort of sandwich with a specially impure "filling" on pure "bread".

The experiments of 1947 were all about refining this idea, and when they were finished they succeeded in producing a "solid state" (semiconductor, not vacuum tube, which is "hollow") amplifier. The device was crude, made of a little of the lucky germanium, gold foil, and a triangle of plastic, but it worked! A small signal could be made into a bigger copy using it.

When they showed it to Shockley, he was surprised. What wasn't a surprise to people who knew him was that he took credit for the discovery and the famous photo of the three of them has Shockley at the bench, a place he never sat, he was a theoretical physicist, not at all at home in the lab. He was brilliant, and contributed a lot due to his deep understanding of the quantum

theory that came, eventually, from Einstein's Annus Mirabilis, but he didn't invent this device. This was a huge accomplishment, and they needed to name the device. They wanted it to sound modern, and cool, but weren't having much success. Many suggestions were made, but John Robinson Pierce (1910–2002) one of the Bell Labs physicists suggested "transistor" for "transfer resistor", and it stuck. The transistor was born.

Shockley, Bardeen, and Brattain shared the Nobel Prize for Physics for its invention, though Shockley's name didn't end p on the patent because he hadn't contributed directly. Even more upsetting was that his own attempt to patent his Lilienfeld-like device, the one he'd made on paper, was blocked by the Lilienfeld patent. He never was much of a financial success, and managed to alienate the people he worked with who went on to form an important next step in your radio: Texas Instruments (TI).

Then, we had to make them cheap…

Producing transistors wasn't easy. The methods to make practical transistors took a long time to work out, and even when they could make them reasonably well "yield" (the number of good ones out of a batch) was fairly low. The only way to make transistors a commercial success was to produce a lot of them so they would be cheap. People from Bell Labs went to Texas to work that out. They had two problems: making transistors, and selling them. Eventually, they worked out the first, but the second was a bit sticky. After the telephone company and the military bought all they could use, there were quite a few left. They needed a customer. Fortunately, one found them.

Finally, we had to put them together…

Masaru Ibuka (1908-1997) was a Japanese scientist who wanted to become a successful businessman. He and Akio Morita (1921-1999) decided to go into the electronics business together, so they formed Tokyo Tsushin Kogyo Kabushiki Kaisha (Tokyo Telecommunications Engineering Corporation) and built tape recorders, a very high tech thing at the time, the first in Japan.

However, in post-war Japan, the real opportunities were trade with the U.S. and they wanted a product for that market. In the early 1950s, Ibuka traveled in the United States to a technical meeting about Bell Labs' new invention: the transistor. He was among the first to license the transistor, and created the first transistor radio (the great-grandfather of your radio!) the TR-63, and he bought all the transistors that TI could make. He and Morita changed the name of the company to "Sony" because they thought "sonny-boy" was a popular phrase in the U.S., and "sonus" means sound in Latin. The transistor radio was a huge success in the U.S. and every teenager wanted one. It was the iPod of the 1950s.

So, while your radio used an integrated circuit (a very large number of transistors in one device), and silicon rather than germanium, which is a better choice for transistors, it's history stretches back to the beginning of radio and electronics. I hope you enjoy the radio, and maybe you will find you have an interest in the technology behind it. Things have changed a lot since Armstrong, and even since Ibuka, but your little Sony radio is the legacy of those men and thousands of others who contributed to all the parts and ideas that make it possible.

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Pretty quickly, though, people started to see that you could do something with radio waves. In particular, you could use them to send information. At the time, the way you sent messages great distances was using the telegraph, developed commercially by Samuel Finley Breese Morse (1791-1872), an American. Telegraphy used long wires stretched between cities and depended on "morse code" (actually invented by his assistant, Alfred Lewis Vail (1807-1859) , which is a way to spell with long and short pulses.

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While Armstrong's life reads like a tragedy, ending in his dramatic suicide, it is a fascinating one, and one of the more fascinating events concerns his wife, Marion McInnis (1898- 1979). Though they had split up when Armstrong became so unstable because of the stress of the lawsuits, and hit her with a fireplace poker. After his death, she pursued and won every one of the suits for her husband even though they only a matter of "moral" victory. A more pleasant connection to your radio is that Armstrong made the first portable radio as a gift for McInnis when they were married.

Armstrong's work revolutionized radio and made commercial broadcasting possible. The creation of the first radio "networks" and the rise of RCA (Radio Corporation of America) is another fascinating story (in which Armstrong figures). But I will leave you to find out about it if you are interested since it is yet-anotherhistory's worth of information. (That's worth learning about!)

From the time that Armstrong's wonderful circuit made radios a practical household item developments in vacuum tubes (the British called them "valves", because the controlled the flow of electrons) developed steadily. Tubes became more powerful and smaller. The advent of World War II brought even more capable and much smaller tubes (called "acorn tubes" because that's what they looked like); but the war also brought something else, something directly connected to your little radio.

Then, we got rid of the tubes…
Of course, even the tiniest "acorn" tubes were much bigger than could fit in your radio. And, not only were they big, they were hot. The filaments in them had been carefully designed to produce more electrons than photons (light waves/particles), which is, of course the idea of a light bulb. But they still had to get hot enough to glow, because it was the heat (therm- from thermionic) that produced the electron stream (-ionic). Heat means power, too. So the batteries that ran portable radios had to be very big, and the voltages required were very high. Your radio runs

from 3 volts, these required 45 volts, and even that had to be converted even higher.

So, tubes weren't very practical for something really portable, and they were inefficient, since a lot of the power needed to run them went into heat. They also didn't last all that long; they burned out just like lightbulbs.

So, what to do about it? Well, in 1905, long before World War II, Albert Einstein (1879-1955) had his "Annus Mirabilis" which means "miracle year" in Latin. It's called that because he wrote four scientific papers which were so far-reaching it took hundreds of scientists decades of work to really understand all the implications of them. Part of the focus was on something called the "photoelectric effect".

This was an observation that when light fell on certain combinations of metals, electricity was produced. This effect was very confusing to scientists because they had concluded that light (which is electromagnetic radiation, just like radio only vibrating a lot faster) travels as waves. Just how waves could do this was quite a mystery. Einstein solved it, but it was very upsetting to the scientists of his time. His solution was to say that light was both waves and particles at the same time. This didn't go over very well because it seemed crazy; but the more it was looked at, the more clear it was that he was right!

These papers began the investigation into Quantum Mechanics, the study of things so small that they are smaller than particles of light itself. You can't see things that are at the quantum level, and they act in very strange ways indeed. In fact, they act so strangely that a prominent scientist declared, "if Einstein is right, science itself is impossible!" Thankfully, he was wrong about that. Einstein was right, and scientists worked it out.

By the time World War II was nearing its end, the people at a really amazing place called Bell Labs, which was the research part of the AT&T's Bell System telephone monopoly, had been working on a project for replacing vacuum tubes in those "repeaters" that first made the Audion tube a commercial success. They needed something more reliable, and lower power. Some of their repeaters were built into the transoceanic cables that ran across the atlantic from America to Europe. Changing a bad tube in a place like that is just a little inconvenient, and powering them meant everything got hotter than they'd like.

So, they were investigating something called "semiconductors". These were materials that were neither conductors nor insulators, but seemed to do some of both.

Conductors allow electric current to flow easily. Most metals are excellent conductors, copper is usually used in wire because it is both a good conductor and not too expensive. It's not cheap either, but it's practical to use. Silver is a better conductor but it costs too much. It is used in special cases, like certain connectors.

Insulators are don't allow electric current to pass; things like rubber, dry wood, and glass are examples. Today, most insulators are man-made materials. Different plastics are very good insulators for low voltages. But if you look up on the poles that carry the power to houses and businesses you will still see glass (and ceramic) insulators for the very high voltages that are

used. (In your neighborhood, before the power gets to your house, it is probably around 15,000 volts, but the receptacles on the walls are only about 1/100 of that, at 120 volts.) Semiconductors, though, are able to conduct sometimes. The first devices made were "diodes" (remember, the Audion was a "triode"). Di- in diode means two. The -ode part is each of the parts (an anode and a cathode). The diode is like a "check valve" used to keep water from backing up in drains, it lets current flow one way, but not the other. The diode is a very useful component, but the real goal was a semiconductor triode, that could act like the tubes and be an amplifier.

Julius Edgar Lilienfeld (1882-1963), who was an Austro-Hungarian born American physicist, received a patent on something he called "Amplifier for electric currents" in 1928. In theory this was what the people at Bell Labs was looking for, a semiconductor triode. In practice, it didn't work. The idea was right, but it couldn't be made. Still, he'd anticipated the work of the team that did make the practical version but more than 20 years.

John Bardeen (1908-1991) and Walter Brattain (1902-1987) were physicists who worked at Bell Labs' Solid State Physics Group under the supervision of William Shockley (1910-1989). Shockley was a brilliant theoretician, but he was also a very greedy man. He wanted fame and fortune, and believed he deserved it. From November to December 1947, Bardeen and Brattain performed practical experiments on the semiconductors in a successful effort to create a working semiconductor amplifier. Shockley, meanwhile, was working on something much more like Lilienfeld's amplifier, all on paper.

Bardeen and Brattain had come to their experiments by a fortunate accident, as is often the case in invention. The materials that were needed for this work had to be very pure. In fact, purifying them was one of the biggest challenges. One of the scientists had gotten a sample of germanium, an early material used in semiconductor production for some tests. He'd connected it to a voltmeter for other reasons, but noticed that if he shined a light on the sample, it produced a very large (relatively speaking) voltage. This was Einstein's photoelectric effect in action, but a much stronger one than they had ever seen.

When they looked careful at the sample, they noticed an irregularity in the middle of it. It seemed to have cooled funny. Probing around, they found that the funny bit in the middle was a little less pure than the ends, forming a "junction" between the two. This was a huge breakthrough. They realized they needed a sort of sandwich with a specially impure "filling" on pure "bread".

The experiments of 1947 were all about refining this idea, and when they were finished they succeeded in producing a "solid state" (semiconductor, not vacuum tube, which is "hollow") amplifier. The device was crude, made of a little of the lucky germanium, gold foil, and a triangle of plastic, but it worked! A small signal could be made into a bigger copy using it.

When they showed it to Shockley, he was surprised. What wasn't a surprise to people who knew him was that he took credit for the discovery and the famous photo of the three of them has Shockley at the bench, a place he never sat, he was a theoretical physicist, not at all at home in the lab. He was brilliant, and contributed a lot due to his deep understanding of the quantum

theory that came, eventually, from Einstein's Annus Mirabilis, but he didn't invent this device. This was a huge accomplishment, and they needed to name the device. They wanted it to sound modern, and cool, but weren't having much success. Many suggestions were made, but John Robinson Pierce (1910–2002) one of the Bell Labs physicists suggested "transistor" for "transfer resistor", and it stuck. The transistor was born.

Shockley, Bardeen, and Brattain shared the Nobel Prize for Physics for its invention, though Shockley's name didn't end p on the patent because he hadn't contributed directly. Even more upsetting was that his own attempt to patent his Lilienfeld-like device, the one he'd made on paper, was blocked by the Lilienfeld patent. He never was much of a financial success, and managed to alienate the people he worked with who went on to form an important next step in your radio: Texas Instruments (TI).

Then, we had to make them cheap…

Producing transistors wasn't easy. The methods to make practical transistors took a long time to work out, and even when they could make them reasonably well "yield" (the number of good ones out of a batch) was fairly low. The only way to make transistors a commercial success was to produce a lot of them so they would be cheap. People from Bell Labs went to Texas to work that out. They had two problems: making transistors, and selling them. Eventually, they worked out the first, but the second was a bit sticky. After the telephone company and the military bought all they could use, there were quite a few left. They needed a customer. Fortunately, one found them.

Finally, we had to put them together…

Masaru Ibuka (1908-1997) was a Japanese scientist who wanted to become a successful businessman. He and Akio Morita (1921-1999) decided to go into the electronics business together, so they formed Tokyo Tsushin Kogyo Kabushiki Kaisha (Tokyo Telecommunications Engineering Corporation) and built tape recorders, a very high tech thing at the time, the first in Japan.

However, in post-war Japan, the real opportunities were trade with the U.S. and they wanted a product for that market. In the early 1950s, Ibuka traveled in the United States to a technical meeting about Bell Labs' new invention: the transistor. He was among the first to license the transistor, and created the first transistor radio (the great-grandfather of your radio!) the TR-63, and he bought all the transistors that TI could make. He and Morita changed the name of the company to "Sony" because they thought "sonny-boy" was a popular phrase in the U.S., and "sonus" means sound in Latin. The transistor radio was a huge success in the U.S. and every teenager wanted one. It was the iPod of the 1950s.

So, while your radio used an integrated circuit (a very large number of transistors in one device), and silicon rather than germanium, which is a better choice for transistors, it's history stretches back to the beginning of radio and electronics. I hope you enjoy the radio, and maybe you will find you have an interest in the technology behind it. Things have changed a lot since Armstrong, and even since Ibuka, but your little Sony radio is the legacy of those men and thousands of others who contributed to all the parts and ideas that make it possible.

A Brief History of Your New Radio
The little radio you hold in your hand is the result of thousands of people's work and ideas. There are a lot of "histories" that could be written about it, here's one of them. I hope you enjoy it.

First, we learned about radio…
In 1887, Heinrich Rudolf Hertz (1857-1894), a German physicist, performed an experiment to test the predictions of two other scientists, James Clerk Maxwell (1831-1879) from Scotland and Michael Faraday (1791-1867) from England the electromagnetic waves should be able to travel through space, and not just through wires.

His experiment was a success, and he was able to show that you could send "radio waves", as they later came to be known, through empty space. At the time it was really only interesting to scientists, no one expected to actually do anything with it.

Then, we figured out a use for it...
Pretty quickly, though, people started to see that you could do something with radio waves. In particular, you could use them to send information. At the time, the way you sent messages great distances was using the telegraph, developed commercially by Samuel Finley Breese Morse (1791-1872), an American. Telegraphy used long wires stretched between cities and depended on "morse code" (actually invented by his assistant, Alfred Lewis Vail (1807-1859) , which is a way to spell with long and short pulses.

Usually, those pulses were the result of a "code key", a kind of switch which caused an electromagnet on the other end go the wire to attract an arm on a device called a "sounder" which makes a click. The operator learns to understand the meaning of the clicks, and can "copy" the code. The telegraph was used to report on the battles of the American Civil War, and changed the way people got news and information, but it was very limited.

About the same time, many people began thinking about "wireless telegraphy". (In fact, while we refer to "radio", the name "wireless", shortened from "wireless" telegraphy is used to talk about the technology, though "radio" is still what we call the stuff we actually listen to.)

The idea of not needing wires to send telegraphic messages was very attractive to businessmen. Scientists are happy with experiments but "inventors" usually want to sell things; and "wireless" looked like it could make someone a lot of money!

Then, we found a way to sell it…
So, right around the turn of the twentieth century, a lot of people were trying to figure out how to make Hertz waves useful and "wireless" possible. People like Nikola Tesla (b. 1856, d. 1943), a brilliant Serbian-born American inventor. Tesla was one of the first practical experimenters in wireless, but, tragically, in spite of his amazing insights and abilities, he died poor and alone, in a hotel room. His life was very interesting, and worth reading about.

Even right here in South Bend in 1899, an Electrical Engineering professor at Notre Dame named Jerome Green made what may be the first long distance radio transmission in the United States. "Long distance" is relative, and his transmission was from the Notre Dame campus to the

Saint Mary's campus, about two miles. He used a very long antenna hung from the side of the basilica, and managed to send the morse code for the letter "S", which is three dots. His attempts to repeat his experiment in Chicago failed, and he blamed the mass of overhead wires used for telephone and telegraph for interfering with the signal. Today, there is an Amateur Radio station called "the Jerome Green Amateur Radio Station (JGARS) which uses the call sign "ND1U" It is part of the College of Engineering. Amateur Radio operators (called "hams") use radios for experimentation, public service, and fun. Becoming a ham is very easy with a little study, and it's a great hobby.

Another inventor early on in radio was Guglielmo Marconi (1874-1937). Marconi was not the brilliant inventor that Tesla was, but he was a far better businessman. Marconi is sometimes considered "the inventor of radio", but this is misleading. He commercialized radio, that is, he found a way to sell it. His experiments and inventions were not necessarily as clever as others, but because he managed to get something built he could sell before others, he was successful. His product was wireless telegraphy, and once he managed to sell his version to the U.S. Navy, he was sure to be a commercial success. But, even with this commercial success, wireless was still just telegraphy, and expensive, and only used when you really needed it (in particular, by ships at sea, where wires just won't do). Then, we made it talk…

By this time, the telephone was also in regular use, having appeared as a device for local use (it couldn't compete yet with the distance that the telegraph could manage). But it didn't take much to imagine "wireless telephony" as the next step. Making it work, though, was another matter. One of the very little known inventor-heroes of radio is a man named Jozef Murgaš (1864-1929). He was a Slovak, and a Catholic Priest who came to America and lived in Wilkes-Barre Pennsylvania. He was also a prolific and brilliant inventor, particularly of radio devices. His story is something like Tesla's because he wasn't a very good businessman and so he gets little credit for his work, but, unlike Tesla, his end was not tragic. He was happy with what he accomplished, even if he never became famous.

Father Murgaš started with wireless early on, and right away he invented a twotone system of telegraphy far more effective than the morse code. This system allowed people who knew it to transmit text about five times faster than the morse code used by Marconi's system. Even though it was far better, Marconi had locked in his system by selling it to the U.S. Navy who wasn't willing to throw away the equipment they'd spent so much on. So, outside local enthusiasts, Murgaš' system was never adopted.

Murgaš may also have been the first in the United States to make a voice transmission. He holds U.S. Patent 1,196,969 on a device that helped make this possible. While he never managed to successfully sell his work, it didn't bother him, he was happy with his life. However, others were watching him very carefully because they saw something they could use to make themselves rich (and famous, which, it turns out, is just as important to that sort of person). Thomas Alva Edison (1847-1931) was one of those people. You might know Edison as "the inventor of the light bulb". This isn't quite right. Once again, like Marconi, Edison was a commercializer. Edison was a prolific inventor in his own right, and he is worth reading about. But the main part of his genius was recognizing and selling good ideas. Edison watched Murgaš carefully, and even spoke with Marconi about what he was up to. Murgaš may not get the credit, but he was a very

important inspiration to other inventors who eventually managed to sell his ideas in various forms, and so get both the credit and the money. But, all of efforts to make radio "talk" were hampered by a big problem: tiny signals. To make wireless telephony useful, some way to was needed distinguish between "signal" (the information, in this case human speech) and "noise" (all of the "non-information" which came from many sources, natural and man-made, remember Professor Green's trouble in Chicago).

Different things were tried, which mostly involved "tuning" the "wireless set" (receiver) better. Making it listen to a smaller portion of the electromagnetic spectrum was the first problem that was tackled. The knob on your radio that allows you to "choose a station" is all about that. It moves a little "window of listening" up and down the band, and the stations each have their spot. This was a very new idea back then, and much more crude, but it helped. It wasn't enough, though, to really make things work well. Somehow, the signal had to be "amplified", that is, made stronger so it could be heard. Then, we found that the light bulb had a secret…

Edison's method of invention was what we would call today, "brute force" (or, if you want to be all scientific about it, "empirical"). When he was commercializing the light bulb, (it had already been "invented", he was trying to make one he could sell), he made hundreds of different versions using all sorts of materials for the "filament" (the glowing part). He tried everything from burnt string to, eventually, tungsten metal which is what he settled on, and what "incandescent" lamps use today (they may be gone in your lifetime as new technologies like CFL (Compact Fluorescent), LED (Light-Emitting Diode), and even more exotic, efficient technologies replace them).

Somewhere along the way, for reasons that aren't clear, he included a piece of wire in the bulb above the glowing filament and sticking out of the top. When he touched it, accidentally he got a shock. This surprised him since the wire wasn't touching the filament. Edison kept meticulous notes, so he wrote it down. It didn't mean anything to him, though, so he also forgot about it. Lee de Forest (1873-1961) noticed it, though. De Forest was an American inventor, something like Edison, in that he was an empiricist. He managed to make useful things without really understanding them well. He wasn't brilliant, like Tesla, but he was persistent, and very interested in personal and commercial success. De Forest realized the there was electrical current flowing from the filament to the wire (in what is called a "thermionic stream"). If a smaller voltage (like the weak radio signal that was a voice) could somehow control that flow, to would be possible to "amplify" it. The small signal could be used to make a bigger copy of itself.

De Forest invented what he called the "Audion" which was just this sort of amplifier. By putting a "grid" between the filament and the wire, he could put a small signal on the grid and influence the flow from the filament to the wire. This was a huge advance, even if he didn't really understand how it worked, other people figured out how to use it. In particular, the telephone companies found it very useful because, remember, they couldn't make phone calls go very far, and "repeaters" that amplified the signal made Long Distance possible. De Forest got quite rich from this, but, he still didn't understand his own work.

On the other hand, Edwin Howard Armstrong (b.1890, d. 1954) did understand it. He was a truly brilliant American electrical engineer who saw the real power of the Audion (technically called a

"triode" because it has three elements). His deep insights into the operation of the triode allowed him to develop something called the "regenerative receiver", which made broadcast radio (the kind you like) practical.

He also invented FM (Frequency Modulation) which is far more pleasant for broadcasts than the AM (Amplitude Modulation) that was used until then. We still use it today, but for talk radio where "fidelity" isn't important, while FM is used for music because it is quieter and can reproduce a wider range of sounds.

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However, in post-war Japan, the real opportunities were trade with the U.S. and they wanted a product for that market. In the early 1950s, Ibuka traveled in the United States to a technical meeting about Bell Labs' new invention: the transistor. He was among the first to license the transistor, and created the first transistor radio (the great-grandfather of your radio!) the TR-63, and he bought all the transistors that TI could make. He and Morita changed the name of the company to "Sony" because they thought "sonny-boy" was a popular phrase in the U.S., and "sonus" means sound in Latin. The transistor radio was a huge success in the U.S. and every teenager wanted one. It was the iPod of the 1950s.

So, while your radio used an integrated circuit (a very large number of transistors in one device), and silicon rather than germanium, which is a better choice for transistors, it's history stretches back to the beginning of radio and electronics. I hope you enjoy the radio, and maybe you will find you have an interest in the technology behind it. Things have changed a lot since Armstrong, and even since Ibuka, but your little Sony radio is the legacy of those men and thousands of others who contributed to all the parts and ideas that make it possible.

A Brief History of Your New Radio

The little radio you hold in your hand is the result of thousands of people's work and ideas. There are a lot of "histories" that could be written about it, here's one of them. I hope you enjoy it.

First, we learned about radio…

In 1887, Heinrich Rudolf Hertz (1857-1894), a German physicist, performed an experiment to test the predictions of two other scientists, James Clerk Maxwell (1831-1879) from Scotland and Michael Faraday (1791-1867) from England the electromagnetic waves should be able to travel through space, and not just through wires.

His experiment was a success, and he was able to show that you could send "radio waves", as they later came to be known, through empty space. At the time it was really only interesting to scientists, no one expected to actually do anything with it.

Then, we figured out a use for it...

Pretty quickly, though, people started to see that you could do something with radio waves. In particular, you could use them to send information. At the time, the way you sent messages great distances was using the telegraph, developed commercially by Samuel Finley Breese Morse (1791-1872), an American. Telegraphy used long wires stretched between cities and depended on "morse code" (actually invented by his assistant, Alfred Lewis Vail (1807-1859) , which is a way to spell with long and short pulses.

Usually, those pulses were the result of a "code key", a kind of switch which caused an electromagnet on the other end go the wire to attract an arm on a device called a "sounder" which makes a click. The operator learns to understand the meaning of the clicks, and can "copy" the code. The telegraph was used to report on the battles of the American Civil War, and changed the way people got news and information, but it was very limited.

About the same time, many people began thinking about "wireless telegraphy". (In fact, while we refer to "radio", the name "wireless", shortened from "wireless" telegraphy is used to talk about the technology, though "radio" is still what we call the stuff we actually listen to.)

The idea of not needing wires to send telegraphic messages was very attractive to businessmen. Scientists are happy with experiments but "inventors" usually want to sell things; and "wireless" looked like it could make someone a lot of money!

Then, we found a way to sell it…

So, right around the turn of the twentieth century, a lot of people were trying to figure out how to make Hertz waves useful and "wireless" possible. People like Nikola Tesla (b. 1856, d. 1943), a brilliant Serbian-born American inventor. Tesla was one of the first practical experimenters in wireless, but, tragically, in spite of his amazing insights and abilities, he died poor and alone, in a hotel room. His life was very interesting, and worth reading about.

Even right here in South Bend in 1899, an Electrical Engineering professor at Notre Dame named Jerome Green made what may be the first long distance radio transmission in the United States. "Long distance" is relative, and his transmission was from the Notre Dame campus to the

Saint Mary's campus, about two miles. He used a very long antenna hung from the side of the basilica, and managed to send the morse code for the letter "S", which is three dots. His attempts to repeat his experiment in Chicago failed, and he blamed the mass of overhead wires used for telephone and telegraph for interfering with the signal. Today, there is an Amateur Radio station called "the Jerome Green Amateur Radio Station (JGARS) which uses the call sign "ND1U" It is part of the College of Engineering. Amateur Radio operators (called "hams") use radios for experimentation, public service, and fun. Becoming a ham is very easy with a little study, and it's a great hobby.

Another inventor early on in radio was Guglielmo Marconi (1874-1937). Marconi was not the brilliant inventor that Tesla was, but he was a far better businessman. Marconi is sometimes considered "the inventor of radio", but this is misleading. He commercialized radio, that is, he found a way to sell it. His experiments and inventions were not necessarily as clever as others, but because he managed to get something built he could sell before others, he was successful. His product was wireless telegraphy, and once he managed to sell his version to the U.S. Navy, he was sure to be a commercial success. But, even with this commercial success, wireless was still just telegraphy, and expensive, and only used when you really needed it (in particular, by ships at sea, where wires just won't do). Then, we made it talk…

By this time, the telephone was also in regular use, having appeared as a device for local use (it couldn't compete yet with the distance that the telegraph could manage). But it didn't take much to imagine "wireless telephony" as the next step. Making it work, though, was another matter. One of the very little known inventor-heroes of radio is a man named Jozef Murgaš (1864-1929). He was a Slovak, and a Catholic Priest who came to America and lived in Wilkes-Barre Pennsylvania. He was also a prolific and brilliant inventor, particularly of radio devices. His story is something like Tesla's because he wasn't a very good businessman and so he gets little credit for his work, but, unlike Tesla, his end was not tragic. He was happy with what he accomplished, even if he never became famous.

Father Murgaš started with wireless early on, and right away he invented a twotone system of telegraphy far more effective than the morse code. This system allowed people who knew it to transmit text about five times faster than the morse code used by Marconi's system. Even though it was far better, Marconi had locked in his system by selling it to the U.S. Navy who wasn't willing to throw away the equipment they'd spent so much on. So, outside local enthusiasts, Murgaš' system was never adopted.

Murgaš may also have been the first in the United States to make a voice transmission. He holds U.S. Patent 1,196,969 on a device that helped make this possible. While he never managed to successfully sell his work, it didn't bother him, he was happy with his life. However, others were watching him very carefully because they saw something they could use to make themselves rich (and famous, which, it turns out, is just as important to that sort of person). Thomas Alva Edison (1847-1931) was one of those people. You might know Edison as "the inventor of the light bulb". This isn't quite right. Once again, like Marconi, Edison was a commercializer. Edison was a prolific inventor in his own right, and he is worth reading about. But the main part of his genius was recognizing and selling good ideas. Edison watched Murgaš carefully, and even spoke with Marconi about what he was up to. Murgaš may not get the credit, but he was a very

important inspiration to other inventors who eventually managed to sell his ideas in various forms, and so get both the credit and the money. But, all of efforts to make radio "talk" were hampered by a big problem: tiny signals. To make wireless telephony useful, some way to was needed distinguish between "signal" (the information, in this case human speech) and "noise" (all of the "non-information" which came from many sources, natural and man-made, remember Professor Green's trouble in Chicago).

Different things were tried, which mostly involved "tuning" the "wireless set" (receiver) better. Making it listen to a smaller portion of the electromagnetic spectrum was the first problem that was tackled. The knob on your radio that allows you to "choose a station" is all about that. It moves a little "window of listening" up and down the band, and the stations each have their spot. This was a very new idea back then, and much more crude, but it helped. It wasn't enough, though, to really make things work well. Somehow, the signal had to be "amplified", that is, made stronger so it could be heard. Then, we found that the light bulb had a secret…

Edison's method of invention was what we would call today, "brute force" (or, if you want to be all scientific about it, "empirical"). When he was commercializing the light bulb, (it had already been "invented", he was trying to make one he could sell), he made hundreds of different versions using all sorts of materials for the "filament" (the glowing part). He tried everything from burnt string to, eventually, tungsten metal which is what he settled on, and what "incandescent" lamps use today (they may be gone in your lifetime as new technologies like CFL (Compact Fluorescent), LED (Light-Emitting Diode), and even more exotic, efficient technologies replace them).

Somewhere along the way, for reasons that aren't clear, he included a piece of wire in the bulb above the glowing filament and sticking out of the top. When he touched it, accidentally he got a shock. This surprised him since the wire wasn't touching the filament. Edison kept meticulous notes, so he wrote it down. It didn't mean anything to him, though, so he also forgot about it. Lee de Forest (1873-1961) noticed it, though. De Forest was an American inventor, something like Edison, in that he was an empiricist. He managed to make useful things without really understanding them well. He wasn't brilliant, like Tesla, but he was persistent, and very interested in personal and commercial success. De Forest realized the there was electrical current flowing from the filament to the wire (in what is called a "thermionic stream"). If a smaller voltage (like the weak radio signal that was a voice) could somehow control that flow, to would be possible to "amplify" it. The small signal could be used to make a bigger copy of itself.

De Forest invented what he called the "Audion" which was just this sort of amplifier. By putting a "grid" between the filament and the wire, he could put a small signal on the grid and influence the flow from the filament to the wire. This was a huge advance, even if he didn't really understand how it worked, other people figured out how to use it. In particular, the telephone companies found it very useful because, remember, they couldn't make phone calls go very far, and "repeaters" that amplified the signal made Long Distance possible. De Forest got quite rich from this, but, he still didn't understand his own work.

On the other hand, Edwin Howard Armstrong (b.1890, d. 1954) did understand it. He was a truly brilliant American electrical engineer who saw the real power of the Audion (technically called a

"triode" because it has three elements). His deep insights into the operation of the triode allowed him to develop something called the "regenerative receiver", which made broadcast radio (the kind you like) practical.

He also invented FM (Frequency Modulation) which is far more pleasant for broadcasts than the AM (Amplitude Modulation) that was used until then. We still use it today, but for talk radio where "fidelity" isn't important, while FM is used for music because it is quieter and can reproduce a wider range of sounds.

Armstrong got into a legal fight with de Forest over the patent on this new circuit. Unfortunately, Armstrong was an ideologue, that is, he believed that if something was "right" he should fight for it to the end. So, instead of making a deal with de Forest, which would have still allowed him to profit from his invention, he felt he needed to "win". He fought de Forest (who had a lot of money to spend and an even bigger idea of how important he was) in the courts, and eventually, he lost the case on a technicality. It was devastating to Armstrong, who lost his marriage, and eventually his life over it. A great tragedy which once again showed how the commercially successful can keep the truly brilliant from contributing.

While Armstrong's life reads like a tragedy, ending in his dramatic suicide, it is a fascinating one, and one of the more fascinating events concerns his wife, Marion McInnis (1898- 1979). Though they had split up when Armstrong became so unstable because of the stress of the lawsuits, and hit her with a fireplace poker. After his death, she pursued and won every one of the suits for her husband even though they only a matter of "moral" victory. A more pleasant connection to your radio is that Armstrong made the first portable radio as a gift for McInnis when they were married.

Armstrong's work revolutionized radio and made commercial broadcasting possible. The creation of the first radio "networks" and the rise of RCA (Radio Corporation of America) is another fascinating story (in which Armstrong figures). But I will leave you to find out about it if you are interested since it is yet-anotherhistory's worth of information. (That's worth learning about!)

From the time that Armstrong's wonderful circuit made radios a practical household item developments in vacuum tubes (the British called them "valves", because the controlled the flow of electrons) developed steadily. Tubes became more powerful and smaller. The advent of World War II brought even more capable and much smaller tubes (called "acorn tubes" because that's what they looked like); but the war also brought something else, something directly connected to your little radio.

Then, we got rid of the tubes…

Of course, even the tiniest "acorn" tubes were much bigger than could fit in your radio. And, not only were they big, they were hot. The filaments in them had been carefully designed to produce more electrons than photons (light waves/particles), which is, of course the idea of a light bulb. But they still had to get hot enough to glow, because it was the heat (therm- from thermionic) that produced the electron stream (-ionic). Heat means power, too. So the batteries that ran portable radios had to be very big, and the voltages required were very high. Your radio runs

from 3 volts, these required 45 volts, and even that had to be converted even higher.

So, tubes weren't very practical for something really portable, and they were inefficient, since a lot of the power needed to run them went into heat. They also didn't last all that long; they burned out just like lightbulbs.

So, what to do about it? Well, in 1905, long before World War II, Albert Einstein (1879-1955) had his "Annus Mirabilis" which means "miracle year" in Latin. It's called that because he wrote four scientific papers which were so far-reaching it took hundreds of scientists decades of work to really understand all the implications of them. Part of the focus was on something called the "photoelectric effect".

This was an observation that when light fell on certain combinations of metals, electricity was produced. This effect was very confusing to scientists because they had concluded that light (which is electromagnetic radiation, just like radio only vibrating a lot faster) travels as waves. Just how waves could do this was quite a mystery. Einstein solved it, but it was very upsetting to the scientists of his time. His solution was to say that light was both waves and particles at the same time. This didn't go over very well because it seemed crazy; but the more it was looked at, the more clear it was that he was right!

These papers began the investigation into Quantum Mechanics, the study of things so small that they are smaller than particles of light itself. You can't see things that are at the quantum level, and they act in very strange ways indeed. In fact, they act so strangely that a prominent scientist declared, "if Einstein is right, science itself is impossible!" Thankfully, he was wrong about that. Einstein was right, and scientists worked it out.

By the time World War II was nearing its end, the people at a really amazing place called Bell Labs, which was the research part of the AT&T's Bell System telephone monopoly, had been working on a project for replacing vacuum tubes in those "repeaters" that first made the Audion tube a commercial success. They needed something more reliable, and lower power. Some of their repeaters were built into the transoceanic cables that ran across the atlantic from America to Europe. Changing a bad tube in a place like that is just a little inconvenient, and powering them meant everything got hotter than they'd like.

So, they were investigating something called "semiconductors". These were materials that were neither conductors nor insulators, but seemed to do some of both.

Conductors allow electric current to flow easily. Most metals are excellent conductors, copper is usually used in wire because it is both a good conductor and not too expensive. It's not cheap either, but it's practical to use. Silver is a better conductor but it costs too much. It is used in special cases, like certain connectors.

Insulators are don't allow electric current to pass; things like rubber, dry wood, and glass are examples. Today, most insulators are man-made materials. Different plastics are very good insulators for low voltages. But if you look up on the poles that carry the power to houses and businesses you will still see glass (and ceramic) insulators for the very high voltages that are

used. (In your neighborhood, before the power gets to your house, it is probably around 15,000 volts, but the receptacles on the walls are only about 1/100 of that, at 120 volts.) Semiconductors, though, are able to conduct sometimes. The first devices made were "diodes" (remember, the Audion was a "triode"). Di- in diode means two. The -ode part is each of the parts (an anode and a cathode). The diode is like a "check valve" used to keep water from backing up in drains, it lets current flow one way, but not the other. The diode is a very useful component, but the real goal was a semiconductor triode, that could act like the tubes and be an amplifier.

Julius Edgar Lilienfeld (1882-1963), who was an Austro-Hungarian born American physicist, received a patent on something he called "Amplifier for electric currents" in 1928. In theory this was what the people at Bell Labs was looking for, a semiconductor triode. In practice, it didn't work. The idea was right, but it couldn't be made. Still, he'd anticipated the work of the team that did make the practical version but more than 20 years.

John Bardeen (1908-1991) and Walter Brattain (1902-1987) were physicists who worked at Bell Labs' Solid State Physics Group under the supervision of William Shockley (1910-1989). Shockley was a brilliant theoretician, but he was also a very greedy man. He wanted fame and fortune, and believed he deserved it. From November to December 1947, Bardeen and Brattain performed practical experiments on the semiconductors in a successful effort to create a working semiconductor amplifier. Shockley, meanwhile, was working on something much more like Lilienfeld's amplifier, all on paper.

Bardeen and Brattain had come to their experiments by a fortunate accident, as is often the case in invention. The materials that were needed for this work had to be very pure. In fact, purifying them was one of the biggest challenges. One of the scientists had gotten a sample of germanium, an early material used in semiconductor production for some tests. He'd connected it to a voltmeter for other reasons, but noticed that if he shined a light on the sample, it produced a very large (relatively speaking) voltage. This was Einstein's photoelectric effect in action, but a much stronger one than they had ever seen.

When they looked careful at the sample, they noticed an irregularity in the middle of it. It seemed to have cooled funny. Probing around, they found that the funny bit in the middle was a little less pure than the ends, forming a "junction" between the two. This was a huge breakthrough. They realized they needed a sort of sandwich with a specially impure "filling" on pure "bread".

The experiments of 1947 were all about refining this idea, and when they were finished they succeeded in producing a "solid state" (semiconductor, not vacuum tube, which is "hollow") amplifier. The device was crude, made of a little of the lucky germanium, gold foil, and a triangle of plastic, but it worked! A small signal could be made into a bigger copy using it.

When they showed it to Shockley, he was surprised. What wasn't a surprise to people who knew him was that he took credit for the discovery and the famous photo of the three of them has Shockley at the bench, a place he never sat, he was a theoretical physicist, not at all at home in the lab. He was brilliant, and contributed a lot due to his deep understanding of the quantum

theory that came, eventually, from Einstein's Annus Mirabilis, but he didn't invent this device. This was a huge accomplishment, and they needed to name the device. They wanted it to sound modern, and cool, but weren't having much success. Many suggestions were made, but John Robinson Pierce (1910–2002) one of the Bell Labs physicists suggested "transistor" for "transfer resistor", and it stuck. The transistor was born.

Shockley, Bardeen, and Brattain shared the Nobel Prize for Physics for its invention, though Shockley's name didn't end p on the patent because he hadn't contributed directly. Even more upsetting was that his own attempt to patent his Lilienfeld-like device, the one he'd made on paper, was blocked by the Lilienfeld patent. He never was much of a financial success, and managed to alienate the people he worked with who went on to form an important next step in your radio: Texas Instruments (TI).

Then, we had to make them cheap…

Producing transistors wasn't easy. The methods to make practical transistors took a long time to work out, and even when they could make them reasonably well "yield" (the number of good ones out of a batch) was fairly low. The only way to make transistors a commercial success was to produce a lot of them so they would be cheap. People from Bell Labs went to Texas to work that out. They had two problems: making transistors, and selling them. Eventually, they worked out the first, but the second was a bit sticky. After the telephone company and the military bought all they could use, there were quite a few left. They needed a customer. Fortunately, one found them.

Finally, we had to put them together…

Masaru Ibuka (1908-1997) was a Japanese scientist who wanted to become a successful businessman. He and Akio Morita (1921-1999) decided to go into the electronics business together, so they formed Tokyo Tsushin Kogyo Kabushiki Kaisha (Tokyo Telecommunications Engineering Corporation) and built tape recorders, a very high tech thing at the time, the first in Japan.

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Pretty quickly, though, people started to see that you could do something with radio waves. In particular, you could use them to send information. At the time, the way you sent messages great distances was using the telegraph, developed commercially by Samuel Finley Breese Morse (1791-1872), an American. Telegraphy used long wires stretched between cities and depended on "morse code" (actually invented by his assistant, Alfred Lewis Vail (1807-1859) , which is a way to spell with long and short pulses.

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Somewhere along the way, for reasons that aren't clear, he included a piece of wire in the bulb above the glowing filament and sticking out of the top. When he touched it, accidentally he got a shock. This surprised him since the wire wasn't touching the filament. Edison kept meticulous notes, so he wrote it down. It didn't mean anything to him, though, so he also forgot about it. Lee de Forest (1873-1961) noticed it, though. De Forest was an American inventor, something like Edison, in that he was an empiricist. He managed to make useful things without really understanding them well. He wasn't brilliant, like Tesla, but he was persistent, and very interested in personal and commercial success. De Forest realized the there was electrical current flowing from the filament to the wire (in what is called a "thermionic stream"). If a smaller voltage (like the weak radio signal that was a voice) could somehow control that flow, to would be possible to "amplify" it. The small signal could be used to make a bigger copy of itself.

De Forest invented what he called the "Audion" which was just this sort of amplifier. By putting a "grid" between the filament and the wire, he could put a small signal on the grid and influence the flow from the filament to the wire. This was a huge advance, even if he didn't really understand how it worked, other people figured out how to use it. In particular, the telephone companies found it very useful because, remember, they couldn't make phone calls go very far, and "repeaters" that amplified the signal made Long Distance possible. De Forest got quite rich from this, but, he still didn't understand his own work.

On the other hand, Edwin Howard Armstrong (b.1890, d. 1954) did understand it. He was a truly brilliant American electrical engineer who saw the real power of the Audion (technically called a

"triode" because it has three elements). His deep insights into the operation of the triode allowed him to develop something called the "regenerative receiver", which made broadcast radio (the kind you like) practical.

He also invented FM (Frequency Modulation) which is far more pleasant for broadcasts than the AM (Amplitude Modulation) that was used until then. We still use it today, but for talk radio where "fidelity" isn't important, while FM is used for music because it is quieter and can reproduce a wider range of sounds.

Armstrong got into a legal fight with de Forest over the patent on this new circuit. Unfortunately, Armstrong was an ideologue, that is, he believed that if something was "right" he should fight for it to the end. So, instead of making a deal with de Forest, which would have still allowed him to profit from his invention, he felt he needed to "win". He fought de Forest (who had a lot of money to spend and an even bigger idea of how important he was) in the courts, and eventually, he lost the case on a technicality. It was devastating to Armstrong, who lost his marriage, and eventually his life over it. A great tragedy which once again showed how the commercially successful can keep the truly brilliant from contributing.

While Armstrong's life reads like a tragedy, ending in his dramatic suicide, it is a fascinating one, and one of the more fascinating events concerns his wife, Marion McInnis (1898- 1979). Though they had split up when Armstrong became so unstable because of the stress of the lawsuits, and hit her with a fireplace poker. After his death, she pursued and won every one of the suits for her husband even though they only a matter of "moral" victory. A more pleasant connection to your radio is that Armstrong made the first portable radio as a gift for McInnis when they were married.

Armstrong's work revolutionized radio and made commercial broadcasting possible. The creation of the first radio "networks" and the rise of RCA (Radio Corporation of America) is another fascinating story (in which Armstrong figures). But I will leave you to find out about it if you are interested since it is yet-anotherhistory's worth of information. (That's worth learning about!)

From the time that Armstrong's wonderful circuit made radios a practical household item developments in vacuum tubes (the British called them "valves", because the controlled the flow of electrons) developed steadily. Tubes became more powerful and smaller. The advent of World War II brought even more capable and much smaller tubes (called "acorn tubes" because that's what they looked like); but the war also brought something else, something directly connected to your little radio.

Then, we got rid of the tubes…

Of course, even the tiniest "acorn" tubes were much bigger than could fit in your radio. And, not only were they big, they were hot. The filaments in them had been carefully designed to produce more electrons than photons (light waves/particles), which is, of course the idea of a light bulb. But they still had to get hot enough to glow, because it was the heat (therm- from thermionic) that produced the electron stream (-ionic). Heat means power, too. So the batteries that ran portable radios had to be very big, and the voltages required were very high. Your radio runs

from 3 volts, these required 45 volts, and even that had to be converted even higher.

So, tubes weren't very practical for something really portable, and they were inefficient, since a lot of the power needed to run them went into heat. They also didn't last all that long; they burned out just like lightbulbs.

So, what to do about it? Well, in 1905, long before World War II, Albert Einstein (1879-1955) had his "Annus Mirabilis" which means "miracle year" in Latin. It's called that because he wrote four scientific papers which were so far-reaching it took hundreds of scientists decades of work to really understand all the implications of them. Part of the focus was on something called the "photoelectric effect".

This was an observation that when light fell on certain combinations of metals, electricity was produced. This effect was very confusing to scientists because they had concluded that light (which is electromagnetic radiation, just like radio only vibrating a lot faster) travels as waves. Just how waves could do this was quite a mystery. Einstein solved it, but it was very upsetting to the scientists of his time. His solution was to say that light was both waves and particles at the same time. This didn't go over very well because it seemed crazy; but the more it was looked at, the more clear it was that he was right!

These papers began the investigation into Quantum Mechanics, the study of things so small that they are smaller than particles of light itself. You can't see things that are at the quantum level, and they act in very strange ways indeed. In fact, they act so strangely that a prominent scientist declared, "if Einstein is right, science itself is impossible!" Thankfully, he was wrong about that. Einstein was right, and scientists worked it out.

By the time World War II was nearing its end, the people at a really amazing place called Bell Labs, which was the research part of the AT&T's Bell System telephone monopoly, had been working on a project for replacing vacuum tubes in those "repeaters" that first made the Audion tube a commercial success. They needed something more reliable, and lower power. Some of their repeaters were built into the transoceanic cables that ran across the atlantic from America to Europe. Changing a bad tube in a place like that is just a little inconvenient, and powering them meant everything got hotter than they'd like.

So, they were investigating something called "semiconductors". These were materials that were neither conductors nor insulators, but seemed to do some of both.

Conductors allow electric current to flow easily. Most metals are excellent conductors, copper is usually used in wire because it is both a good conductor and not too expensive. It's not cheap either, but it's practical to use. Silver is a better conductor but it costs too much. It is used in special cases, like certain connectors.

Insulators are don't allow electric current to pass; things like rubber, dry wood, and glass are examples. Today, most insulators are man-made materials. Different plastics are very good insulators for low voltages. But if you look up on the poles that carry the power to houses and businesses you will still see glass (and ceramic) insulators for the very high voltages that are

used. (In your neighborhood, before the power gets to your house, it is probably around 15,000 volts, but the receptacles on the walls are only about 1/100 of that, at 120 volts.) Semiconductors, though, are able to conduct sometimes. The first devices made were "diodes" (remember, the Audion was a "triode"). Di- in diode means two. The -ode part is each of the parts (an anode and a cathode). The diode is like a "check valve" used to keep water from backing up in drains, it lets current flow one way, but not the other. The diode is a very useful component, but the real goal was a semiconductor triode, that could act like the tubes and be an amplifier.

Julius Edgar Lilienfeld (1882-1963), who was an Austro-Hungarian born American physicist, received a patent on something he called "Amplifier for electric currents" in 1928. In theory this was what the people at Bell Labs was looking for, a semiconductor triode. In practice, it didn't work. The idea was right, but it couldn't be made. Still, he'd anticipated the work of the team that did make the practical version but more than 20 years.

John Bardeen (1908-1991) and Walter Brattain (1902-1987) were physicists who worked at Bell Labs' Solid State Physics Group under the supervision of William Shockley (1910-1989). Shockley was a brilliant theoretician, but he was also a very greedy man. He wanted fame and fortune, and believed he deserved it. From November to December 1947, Bardeen and Brattain performed practical experiments on the semiconductors in a successful effort to create a working semiconductor amplifier. Shockley, meanwhile, was working on something much more like Lilienfeld's amplifier, all on paper.

Bardeen and Brattain had come to their experiments by a fortunate accident, as is often the case in invention. The materials that were needed for this work had to be very pure. In fact, purifying them was one of the biggest challenges. One of the scientists had gotten a sample of germanium, an early material used in semiconductor production for some tests. He'd connected it to a voltmeter for other reasons, but noticed that if he shined a light on the sample, it produced a very large (relatively speaking) voltage. This was Einstein's photoelectric effect in action, but a much stronger one than they had ever seen.

When they looked careful at the sample, they noticed an irregularity in the middle of it. It seemed to have cooled funny. Probing around, they found that the funny bit in the middle was a little less pure than the ends, forming a "junction" between the two. This was a huge breakthrough. They realized they needed a sort of sandwich with a specially impure "filling" on pure "bread".

The experiments of 1947 were all about refining this idea, and when they were finished they succeeded in producing a "solid state" (semiconductor, not vacuum tube, which is "hollow") amplifier. The device was crude, made of a little of the lucky germanium, gold foil, and a triangle of plastic, but it worked! A small signal could be made into a bigger copy using it.

When they showed it to Shockley, he was surprised. What wasn't a surprise to people who knew him was that he took credit for the discovery and the famous photo of the three of them has Shockley at the bench, a place he never sat, he was a theoretical physicist, not at all at home in the lab. He was brilliant, and contributed a lot due to his deep understanding of the quantum

theory that came, eventually, from Einstein's Annus Mirabilis, but he didn't invent this device. This was a huge accomplishment, and they needed to name the device. They wanted it to sound modern, and cool, but weren't having much success. Many suggestions were made, but John Robinson Pierce (1910–2002) one of the Bell Labs physicists suggested "transistor" for "transfer resistor", and it stuck. The transistor was born.

Shockley, Bardeen, and Brattain shared the Nobel Prize for Physics for its invention, though Shockley's name didn't end p on the patent because he hadn't contributed directly. Even more upsetting was that his own attempt to patent his Lilienfeld-like device, the one he'd made on paper, was blocked by the Lilienfeld patent. He never was much of a financial success, and managed to alienate the people he worked with who went on to form an important next step in your radio: Texas Instruments (TI).

Then, we had to make them cheap…

Producing transistors wasn't easy. The methods to make practical transistors took a long time to work out, and even when they could make them reasonably well "yield" (the number of good ones out of a batch) was fairly low. The only way to make transistors a commercial success was to produce a lot of them so they would be cheap. People from Bell Labs went to Texas to work that out. They had two problems: making transistors, and selling them. Eventually, they worked out the first, but the second was a bit sticky. After the telephone company and the military bought all they could use, there were quite a few left. They needed a customer. Fortunately, one found them.

Finally, we had to put them together…

Masaru Ibuka (1908-1997) was a Japanese scientist who wanted to become a successful businessman. He and Akio Morita (1921-1999) decided to go into the electronics business together, so they formed Tokyo Tsushin Kogyo Kabushiki Kaisha (Tokyo Telecommunications Engineering Corporation) and built tape recorders, a very high tech thing at the time, the first in Japan.

However, in post-war Japan, the real opportunities were trade with the U.S. and they wanted a product for that market. In the early 1950s, Ibuka traveled in the United States to a technical meeting about Bell Labs' new invention: the transistor. He was among the first to license the transistor, and created the first transistor radio (the great-grandfather of your radio!) the TR-63, and he bought all the transistors that TI could make. He and Morita changed the name of the company to "Sony" because they thought "sonny-boy" was a popular phrase in the U.S., and "sonus" means sound in Latin. The transistor radio was a huge success in the U.S. and every teenager wanted one. It was the iPod of the 1950s.

So, while your radio used an integrated circuit (a very large number of transistors in one device), and silicon rather than germanium, which is a better choice for transistors, it's history stretches back to the beginning of radio and electronics. I hope you enjoy the radio, and maybe you will find you have an interest in the technology behind it. Things have changed a lot since Armstrong, and even since Ibuka, but your little Sony radio is the legacy of those men and thousands of others who contributed to all the parts and ideas that make it possible.