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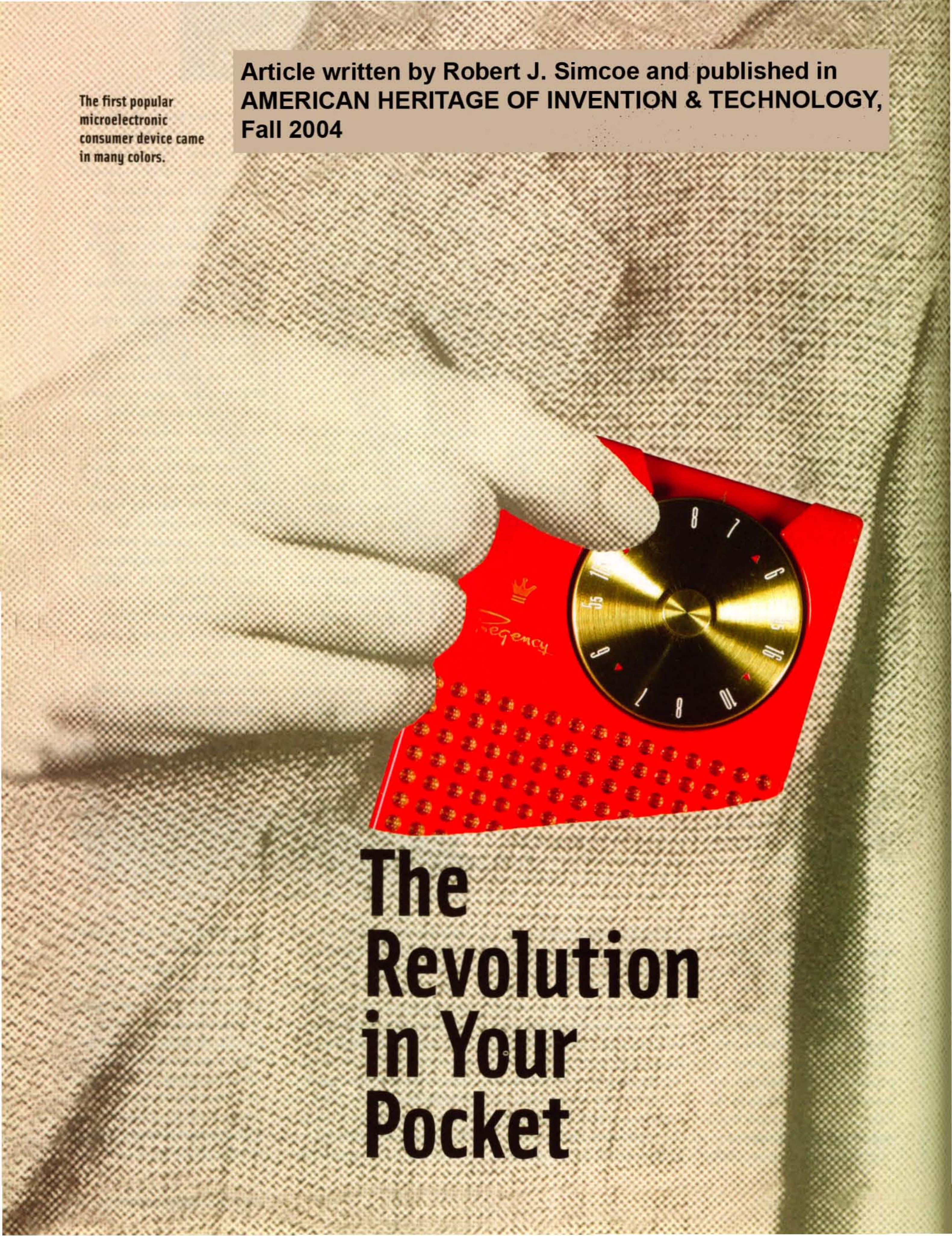
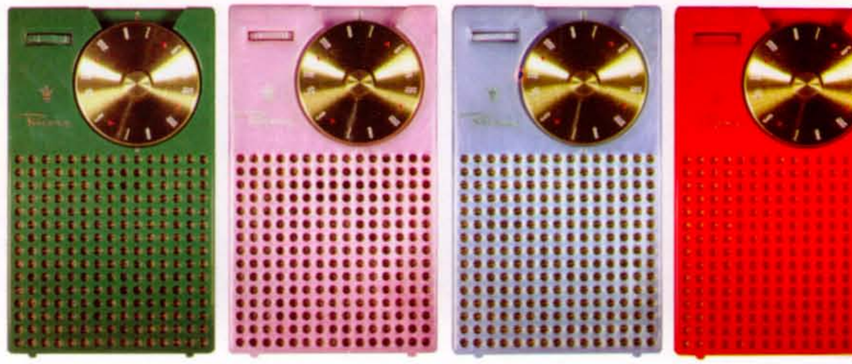


The first popular microelectronic consumer device came in many colors.

The Revolution in Your Pocket



FIFTY YEARS AGO A TRANSISTOR RADIO CALLED THE TR1 STARTED THE REMAKING OF THE WORLD BY SEMICONDUCTORS

BY ROBERT J. SIMCOE

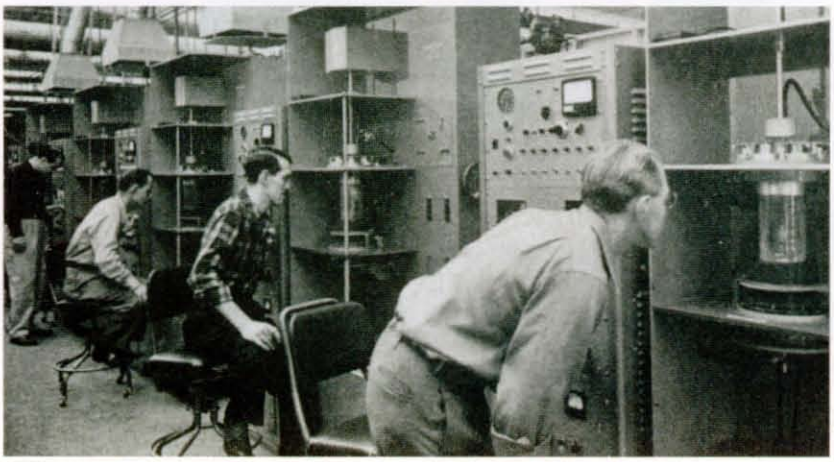
HALF A CENTURY AGO THIS AUTUMN TWO SMALL COMPANIES, working together, unveiled the world's first transistor radio. It was called the Regency TR1. It introduced the revolutionary technology of the transistor to the general public, and it began the spread of all the miniaturized, battery-operated electronic devices that surround us today.

The companies were Texas Instruments and Industrial Development Engineering Associates. TI made instrumentation for the oil industry and locating devices for the Navy; IDEA mainly built home TV antenna boosters, many carrying the Sears Silvertone brand name. But TI wanted to grow from a $20 million company into a $200 million one, and IDEA wanted to get into new product areas. The unlikely pairing of the two companies created, within a very short time, a product that in its styling, its circuit design, its manufacturing technology, and, above all, its use of miniaturized components pointed the way to the future.

Texas Instruments started work on a pocket radio in the spring of 1954, but the seeds of the idea had been planted three years earlier. In 1951 Pat Haggerty, TI's vice president, decided to bet the company by licensing the new technology of the transistor from Bell Laboratories, which had invented it. Haggerty had the vision to see that the little solid-state device would eventually replace the millions of vacuum tubes then at the heart of the fast-growing electronics industry. By 1954 he was eager to get in at the start by establishing a high-volume, high-profile consumer market before anyone else did. He chose the portable AM radio.

The transistor had been invented at Bell Labs by John Bardeen, Walter Brattain, and William Shockley, and it was announced to the world on June 30, 1948. It was made, in the beginning, of germanium, an element whose pure crystalline form is a very good insulator. "Doping" germanium with an impurity could turn it from an insulator into a feeble conductor of electrons, or semiconductor. Depending on the element it was doped with, it either had an excess of electrons and was called N-type (for *negative*) or had a deficit of electrons and was called P-type. If you placed the two types next to each other, you got a P-N junction diode, which would pass electric current in only one direction.

You got a junction transistor (which quickly succeeded the crude original point-contact transistor) by sandwiching three doped regions of germanium to create back-to-back junctions, either N-P-N or P-N-P. This sandwich would block current both ways until a small current was applied to the central region, called the base; then the transistor structure would allow a much larger current to flow through the sandwich as a whole. That meant it could be used as either a switch or an amplifier, the current applied to the base either turning the whole thing on and off as a switch or making it act as an amplifier, with a modest current to the base allowing a corresponding larger current to flow through the whole. Thus a tiny chip of germanium



Scientists at TI keep watch over the crucibles that "grow" junction transistors.

first crude prototype had been unveiled, only about a million germanium transistors had been fabricated by the entire industry. They had gone into a small number of military and commercial applications; the only consumer products were a few hearing-aid amplifiers, whose high price was justified by a savings in batteries, which were very expensive for power-thirsty vacuum-tube hearing aids.

Although TI had made progress with silicon transistors, Haggerty didn't want to wait for them to be ready for mass production. He decided to push for an application for the germanium transistor, one where high-temperature operation wouldn't be necessary. He was confident that manufacturing costs could be brought down fast if volume was high enough, and he believed that anything TI learned making germanium transistors would later help it with silicon ones.

His crucial insight was that getting in early would be more than worth the terrific expense. The company would come out ahead in the marketplace and with experience that would let it quickly increase yields and bring down costs. This involved an especially big investment—and gamble—because Haggerty figured he'd have to price transistors not at what they initially cost to produce but at what they'd cost after production had reached full volume. That would entice the rest of the industry to use them too, and it would force TI's own people to lower those costs as fast as possible. As it turned out, Texas Instruments would follow this strategy with other technologies in the coming years.

In the late spring of 1954 Haggerty committed $2 million (TI's total revenue was about $25 million) to a crash program to produce a portable transistor radio that would sell for about $50, considerably more than a portable tube radio but not unrealistic for a glamorous high-tech novelty. He set up an engineering team under Paul Davis, who had experience designing radios, to produce a prototype design to pass along to manufacturing and marketing partners yet to be found.

Ed Millis, who was a production engineer at TI, writes that "when Pat Haggerty said he wanted a working transistor radio, he didn't mean next year or next month. He meant next week. . . . Haggerty had given Paul [Davis] the challenge late in the afternoon on Friday, May 21, 1954. Despite the fact that Davis had to pull together a team and start with no designs, no specifications, no coils or transformers suitable for transistor use, and no transistors that had been used at these frequencies, his group delivered to Pat Haggerty a working prototype on Tuesday afternoon, May 25."

The design of that working prototype was straightforward. An AM radio picks up waves with an antenna, selectively tunes

(or, later, silicon) could do the same work previously done by a large, hot vacuum tube.

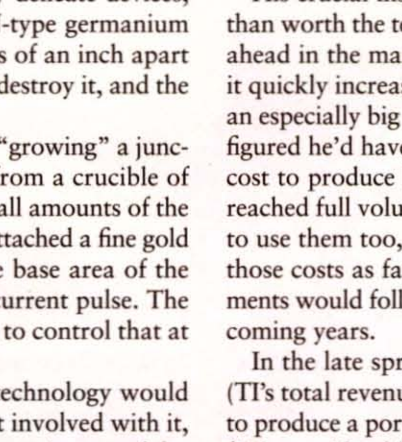
Bell Labs' first transistors were extremely delicate devices, made by contacting a very small chip of N-type germanium crystal with wires spaced a few thousandths of an inch apart through a P-type layer. Dropping one could destroy it, and the contact areas were easily contaminated.

In 1950 Bell's scientists invented a way of "growing" a junction transistor by pulling a "seed" crystal from a crucible of molten germanium and "doping" it with small amounts of the impurity elements as it came out. Bell Labs attached a fine gold wire containing an impurity element to the base area of the transistor by welding it with a quick high-current pulse. The process held promise, but it was so difficult to control that at the outset only one in 20 devices worked.

Executives at Bell Labs figured that the technology would develop much faster if a lot more people got involved with it, so in 1951 they decided to license it to anyone interested for $25,000. Haggerty paid the fee, and Texas Instruments became one of more than two dozen licensees. It was well known that germanium transistors worked poorly at frequencies above 100 kHz when temperatures exceeded 167 degrees, so they would have little use in large industrial and military markets. With that in mind, Haggerty hired Gordon Teal, who had helped develop the techniques for growing semiconductor crystals at Bell Labs, and the physical chemist Willis Adcock to begin work at TI on semiconductors made of silicon. Silicon is an element with the same number of electrons in its outer shell as germanium and therefore has very similar properties, but it worked better at high temperatures. By 1954 TI had made much more progress with silicon than its rivals had thought possible. In May 1954 the company surprised the industry by announcing that it had made silicon transistors that worked.

Now Haggerty was impatient to develop a mass market. In the five years since the

A 1955 magazine illustration shows a cross section of the crucible setup.



THE PROCESS OF MAKING TRANSISTORS WAS SO DIFFICULT THAT AT THE OUTSET IT WORKED ONLY ABOUT A TWENTIETH OF THE TIME.

them in at a desired frequency, amplifies the signal they carry, and sends it to a speaker. The first step didn't amount to much more than having transistors do what tubes had always done. One big innovation was required right off, though: Roger Webster, one of the first team members Davis picked, made a fundamentally new design for the intermediate-frequency transformer, used when the signal is amplified, after it has been tuned in and converted to a new, standardized lower frequency. He both miniaturized the transformer and adapted it to specific characteristics of the transistor. His work became standard for transistor circuits.

THIS FIRST DESIGN USED EIGHT TRANSISTORS. THAT WAS too many for a radio that would sell for only $50, but it would allow the company to show potential partners a working device. Now things got harder. The prototype would have to be made simpler, cheaper, and smaller—and mass-producible. In Ed Millis's words, "As Mr. Haggerty was fond of saying, the reward for a job well done was a harder job, and it didn't take long for Paul Davis and his team to be heavily rewarded. On the following Saturday morning, Pat dropped by Paul's office and asked them to redesign and build their new radio circuit in an empty small Emerson vacuum-tube portable radio case that measured 6 1/4 inches by 3 inches by 1 1/4 inches. But he didn't need it until Monday evening when he was flying to see a customer. . . . Of course, they made this utterly impossible schedule, because Pat Haggerty asked them to. Few people could inspire engineers like Pat."


The fruit of the labors on the opposite page: a completed junction transistor.

Haggerty found a manufacturing partner with the help of Buddy Harris, TI's first marketing manager. According to Harris, "I personally contacted every major radio manufacturer in the United States . . . and got no encouragement from any of them." Then Haggerty noticed a magazine ad for an IDEA antenna booster and decided to approach that company. He and Harris met up with Ed Tudor, IDEA's president, at a trade show in Chicago, and TI finally found a willing partner in the small Indianapolis-based company.

IDEA had talented people designing, manufacturing, and marketing electronic goods for the general public and so made a good complement to TI, with its technical prowess, even if IDEA wasn't as prominent as TI might have wished. IDEA would prove to be a knowledgeable and nimble engineering and marketing partner.

The companies signed an agreement in June 1954 that they'd bring out a radio under IDEA's Regency name in time for Christmas, and announce it in October. This was a tall order for everyone involved. TI had to figure out how to produce high-frequency transistors cheaply and in bulk. Regency had to reduce the prototype radio very fast to something that could be mass-produced very inexpensively.

Richard Koch, Regency's master engineer, was named project leader. Floyd Hayhurst, a colleague who worked closely with him, called him "one fantastic engineer—the type of fellow who, if you assign him to a project, time means nothing; he gets in with both feet and obstacles mean nothing." One main task was to further reduce the number of transistors, which TI now had down to six, and to get rid of any other components that could be eliminated. Early on Koch saw that a diode—sort of a half-transistor—could replace the transistor at the detector stage, where the amplified radio signal got converted into an audio signal. The only tradeoff was a slight loss in amplification.

A radio receiver has to amplify the weak signal the antenna catches about a hundred billion times to get it strong enough to drive a speaker. The standard AM radio, using what is called superheterodyne circuitry, does this in several stages. First an oscillator is tuned to produce an unmodulated frequency. Then the oscillator's signal is mixed with the modulated one from the antenna (the modulations indicating the information being carried) to create a new signal at a lower frequency known as the intermediate frequency. Most of the amplification is done at this lower frequency, by electronics designed to work especially well there.

Traditional superheterodyne designs had used separate tubes for the oscillator and mixer stages. In July Koch invented a circuit that combined both functions using a single transistor. The number of transistors was now down to four, further simplifying production and cutting costs, and the transistor that had just been eliminated was one that was especially hard to make from germanium, because of its high-frequency requirements.

Regency now placed an initial order with TI for 100,000 sets of four transistors. The price tag was $10 per set—even though transistors then cost $10 to $15 apiece. TI color-coded the transistors and individually selected the ones in each set to make sure that together they'd provide enough amplification. Less than 10 percent of the transistors TI was painstakingly producing turned out to be usable, yet the company was going to have to increase its volume dramatically.

"There were dozens of processes that went into this," said Mark Shepard, then the company's manager of transistor development and later its chairman and chief executive. Shepard's workers grew the devices, sawed the crystals into tiny slivers called bars, etched and polished each bar, and then attached the wires. After testing and rejecting most of every lot, they encapsulated the good ones in epoxy and soldered metal lids on them. Then the transistors' performance was measured, and they were individually marked according to the results with spots

FINDING PARTS SMALL ENOUGH TO FIT TOGETHER INSIDE THE CASE WASN'T EASY. ALMOST EVERY COMPONENT REQUIRED INNOVATION.

of paint on their lids and sorted into barrels. "We never threw anything away in those days," Shepard recalled. "Some customers would always come in and want something a little different, and we'd go back through our barrels and fill the order."

Regency engaged a Chicago design firm, Painter, Teague, and Petertil, to come up with a plastic case that could fit into a shirt pocket. Victor Petertil offered several concepts for a box three by five by one and a quarter inches (the pocket would not be a small one). Fabricating the tooling to make the case that was selected went down to the wire; it was ready just barely in time to get prototype production radios out by the contract deadline of October 31.

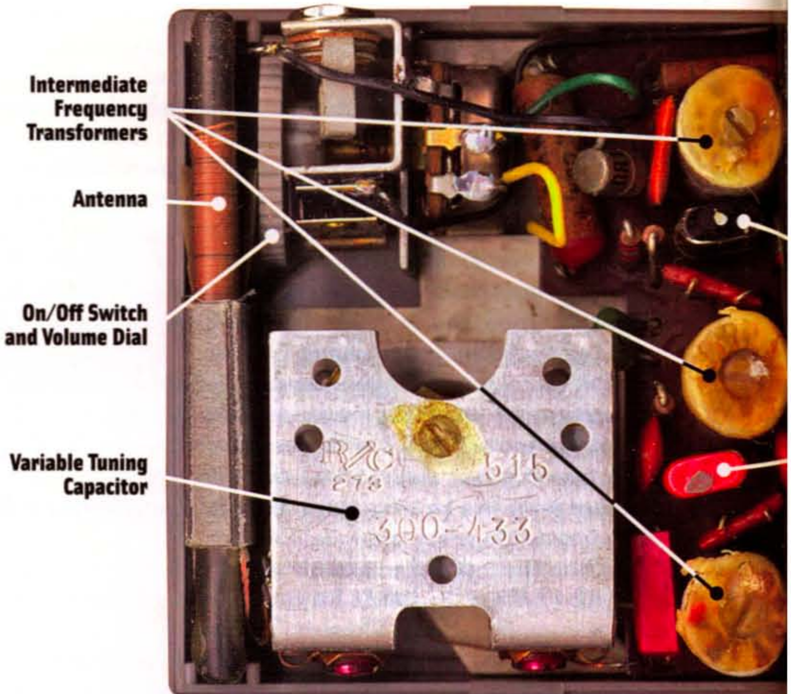
FINDING PARTS SMALL ENOUGH TO FIT TOGETHER INSIDE the case wasn't easy either. Except for resistors, every one of the components required innovation. For instance, Regency planned to use a printed circuit board to connect everything together. This was still a fairly new concept. Paul Eisler, a Viennese engineer, had patented the circuit board in 1943, and it had been used in proximity fuzes during World War II. It had been declassified after the war, but it still had had little commercial use. But for this miniature radio the printed circuit looked more promising than hand-wiring everything.

Ed Tudor, the president of IDEA, noted at a celebration of Texas Instruments' fiftieth anniversary, in 1980: "You may be surprised to know that the Regency radio triggered the miniature discrete components market." One component, the two-stage variable tuning capacitor, made by the Radio Condenser Company, was so small that the manufacturer felt the need to add a set screw for adjusting its shaft. Chicago Telephone Supply, which provided the volume-control dial, didn't have one that was small enough and also had a switch, so Regency molded a cam onto the dial to make it turn the radio on and off. The loudspeaker, from the Jensen speaker company, was at 2 3/4 inches across the smallest anyone had ever produced (not counting earphones). The coils and transformers, all much smaller than in any previous radio, had to be specially designed and hand-built for the TI prototype; Regency then worked with the Vokar Corporation to redesign the transformers so they could be mass-produced.

Perhaps the most vexing problem was finding a supplier of miniature electrolytic capacitors. Capacitors are like tiny batteries; they briefly store electrical energy. Vacuum-tube circuits, relying on variations in voltage, used high-voltage, low-capacitance capacitors to store and release surges of energy; a transistor circuit would need low-voltage, high-capacitance ones. The few out there were very large. Eventually a Nashville company with the grand name International Electronics, Inc., was persuaded to set up a small assembly line to turn them out. Alan M. Holiday, a chemistry professor at Peabody College in Nashville (he was, perhaps inevitably, known as "Doc"), tailored the electrolyte formulation, a paste that goes between sheets of conductors, to greatly increase their electrical-charge storage capacity. Meanwhile, R. Royce Richey, the production manager at International Electronics, found a source in Germany for the very thin aluminum foil that the devices required. Getting them made was yet one more race against time. "For a while," Richey recalled, "I would take each day's output of capacitors to the Nashville airport and send them to Indianapolis so that the production lines could keep going."

The earliest capacitors had the foil and paste in a wax-coated paper tube. Unfortunately the tube was too porous and allowed the water in the electrolyte paste to evaporate, so the capacitors tended to dry out and fail, sometimes within six months. Soon they were being housed in a distinctive white ceramic cylinder sealed with epoxy, but they remained the most likely component in the radio to break down, because their casing was still somewhat porous and their seal could disintegrate with age. Today replacing the capacitors in a nonworking early transistor radio is often the one fix needed to revive it.

Dick Koch found the capacitors such a headache that in the TR6, the next radio he personally designed, he soon got rid of as many as he could. He and Robert Cox, Regency's director of purchasing, designed the TR6 over a couple of hours one afternoon in late 1955. This may have set some kind of record. In that design they used only two electrolytic capacitors, half as many as in the TR1, and those were in sealed aluminum containers. Unlike TR1s, most TR6 radios work to this day.



The TR1 was announced to the world right on schedule on October 18, 1954. When it was launched in New York and Los Angeles, demand quickly outpaced supply; only about 1,500 radios had been made. Still, their appearance left the rest of the electronics industry playing catch-up. Raytheon, Bulova, General Electric, Emerson, and RCA all scrambled to produce competing products, and they announced them throughout 1955. Over the next year or so Regency produced at least 100,000 TR1s, far fewer than the 20 million over three years that Regency's marketing director had predicted they would sell, but that estimate had been based partly on the erroneous assumption that people would clamor for them for their bomb shelters.

Pat Haggerty and Ed Tudor congratulate each other on the completion of their project in late 1954.

Within a few years both TI and IDEA gave up on consumer transistor radios. They hadn't ever become very profitable. Still, both companies had met their goals. At TI's fiftieth anniversary celebration, Pat Haggerty remarked: "We broke even. We came out of it without it costing anything. We had launched the business, and that's exactly what we set out to do. But it was a strategic mistake. The facts are that at $60 or $65 it wouldn't have made an iota of difference. And had those radios sold at that price, a price related to the value and interest of the consumer, a lot of other things probably would have happened. . . . Had we each had the additional hundreds of thousands of dollars that the difference in pricing would have made available, and hence the funds to go on and develop additional products, we probably would have . . . stayed in the consumer business. I think the likelihood is very high that we would have been the Sony of consumer electronics."

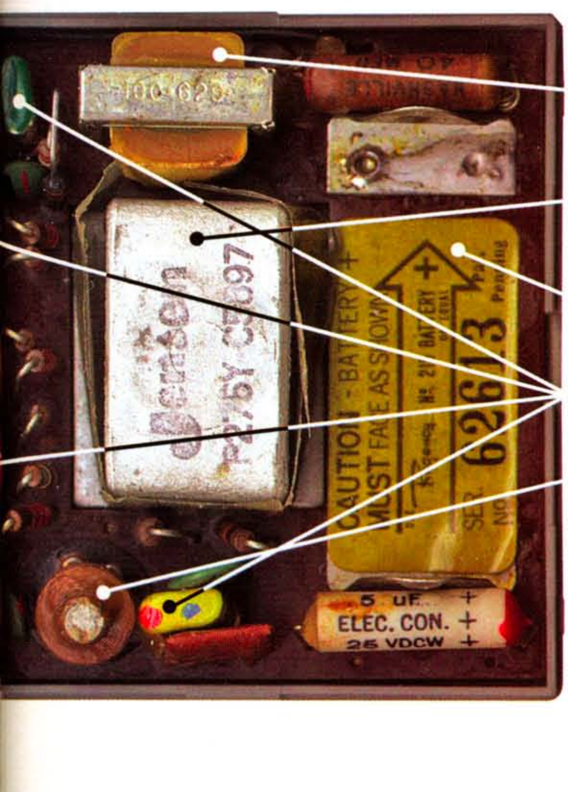
Texas Instruments did go on to great success, quickly becoming a powerhouse of the semiconductor industry. It manufactured millions of individual transistors for Regency, IBM (whose chairman and chief executive, Thomas J. Watson, Jr., handed out TR1 radios to prod his staff to design all their new computers with transistors), and the rest of the electronics industry. It also was highly successful manufacturing the integrated circuits, loaded with transistors and other components, that its own Jack Kilby invented in 1958. And TI drew on its TR1 experience when it went into other consumer products like calculators and electronic watches.

Regency followed the TR1 with a succession of radios, the TR1G, TR4, TR5, and others. Along the way the company sold its radio patents and resistor division to TI, and by 1961 Regency had given up on AM radios in favor of commercial and citizens-band ones. Today IDEA/Regency is RELM Wireless, a maker of two-way radios. TI of course remains the semiconductor giant that Pat Haggerty envisioned.

Every once in a while something special happens, and some human endeavor achieves a level so far above what went before that it sets a new standard. The design, development, and manufacturing of the TR1 was one of those moments. Although the TR1 was rushed out under intense self-imposed time pressure, its execution was superb. Even the radio's case has a classic simplicity; its aesthetics have stood the test of time. The engineering inside is excellent too. And even if it didn't sell in the millions, the radio was a hit.

In 1955, the TR1's first full year on the market, TI made half as many transistors for that radio alone as had previously been made by the whole industry. Today a single Intel P4 microprocessor chip in your computer, with about 125 million transistors, has more than several hundred times as many as TI made that year. The average American home contains dozens of hand-held, battery-operated subminiaturized devices that each hold hundreds of thousands or millions of transistors.

Walter Brattain, one of the inventors of the transistor, once observed: "Even the loneliest nomad on the steppes of Asia can have the news of the world by twisting a dial. He doesn't have to read. Once the common man has a chance to learn what is going on, he has a chance to control his destiny." Today a transistor radio is so inexpensive that virtually anyone anywhere can be connected to the whole world. The TR1 was a big first step toward all of that. ★



Inside the TR1. Most of the unlabeled components are capacitors and resistors.

ROBERT J. SIMCOE *worked for 37 years designing semiconductor devices for the computer and network industries. He is currently working on a scanner to digitize the Harvard College Observatory's photographic-plate collection.*

TOP: COURTESY OF TEXAS INSTRUMENTS

LOOK, MA, NO TUBES

The first transistor radio, introduced 50 years ago this fall, ushered in the silicon age even though its transistors were made of germanium. To read how the Regency TR1 went from idea to store shelves in a few months, see page 12.

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