

Transistor History

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From Transistor to Spacistor

Semiconductor Research and Development at Raytheon

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Raytheon began as a tube manufacturer in the 1922 but established its reputation through its World War Two development of magnetrons and radars, and in the post war era, the development of guided missile systems.

It responded quickly to the public announcement of Bell Laboratories' invention of the transistor. With an entrepreneur's vision and energy it acquired all the resources and processes to become the World's leading producer of transistors in the early 1950s. But it could not maintain its leadership and decided to withdraw from semiconductor markets in 1962.

This is the story of how Raytheon achieved its spectacular success in semiconductors and the market forces and choices that caused the demise of its semiconductor business in little more than a decade. The author is very grateful for the assistance from longstanding collectors and researchers of the history of semiconductors acknowledged at the end of this article.

Raytheon the Company



Raytheon was founded by Laurence Marshall, Vannevar Bush and Charles Smith in 1922 and was originally known as the American Appliance Company. It was formed to develop a refrigerator with no moving parts. This was unsuccessful and the founders elected to begin making gas filled tubes designed for "battery eliminators" that enabled early vacuum tube radio sets to run without expensive high voltage "B" batteries. The tube was launched late in 1925 with the claim "*Revolutionizing the B-Eliminator.*" The new direction was celebrated with a new company name: Raytheon and it concentrated on vacuum tubes. [Stokes 1982 Photo courtesy of Joe Knight]

In 1928 Laurence Marshall became the company president and remained in this position until 1948.

Percy Spencer became a key figure through his innovations in tube design and production. He redesigned the B rectifier which became the BH and the BA enabling higher operating voltages and introduced a line of transmitting tubes. His innovations in magnetron design and production created a platform for Raytheon's success in radar during the Second World War.

In 1938 Percy Spencer also designed a range of miniature tubes intended for portable applications such as hearing aids. Ruggedized versions of these were used in proximity fuses that revolutionised artillery during the War. Raytheon's experience in the hearing aid market and understanding of its needs was a key factor in their aggressive response to the opportunity created by the transistor in 1948.

In 1942 Raytheon built its first radar set, the SG, widely deployed by the Allied navies in 1943. The SO, a smaller model, appeared shortly afterwards. Production reached a maximum by 1944 and at its war time peak the company employed 18,000 workers; but employment had dropped to 3,500 by 1946.

So Marshall diversified the company into consumer products: he purchased the Belmont Radio Company and the Russell Electric Company that produced phonograph parts. He established a network of microwave sites that he intended would support television and FM radio networks.

Raytheon found peacetime uses for wartime technologies. It had been noticed that microwaves generated by radar sets caused heating; an observation that led Raytheon to invent the microwave oven which was sold under the Radarange brand.

In 1946 the company merged with another major war time contractor facing diminishing revenues: the Submarine Signal Company which specialised in sonar. The architect of the merger, Charles Adams, was invited to join the board of the expanded company and two years later replaced Marshall as president. Marshall left the company in 1950.

The military is imbedded in Raytheon's DNA. In 1948 Raytheon began a guided missile programme and in 1950 it successfully demonstrated that its Lark missile guidance system could destroy an aircraft in flight. Development of a succession of air to air and ground to air missiles was accelerated by the Korean War.

Raytheon grew thanks to the exceptionally entrepreneurial leadership of Laurence Marshall, the risks he was prepared to take and the opportunities that arose out of the Second World War, the Korean War and the Cold War. Its core technology evolved from tubes to magnetrons and radar then to missile guidance systems.

Raytheon was never a semiconductors company: its histories scarcely mention them. Radar crystal detectors were an important element in the development of radar but Raytheon will be remembered for its ability to devise the means to mass produce the magnetron and to build battle ready radars and guided missiles.

The Semiconductor Era

The point-contact transistor was first developed and demonstrated at Bell Laboratories in December 1947 representing the first fragile entrant of the semiconductor age. In the ensuing months further work was carried out in

support of a patent application which, when in place, would enable Bell to announce its breakthrough to the World.

In a carefully orchestrated programme, Bell first disclosed its invention to a gathering of representatives from the Army, Navy and Air Force on 23rd June 1948. On the 30th of June a similar presentation was made to the mainstream and technical media. This was calculated to make an impact: reporters were invited to listen to the commentary on earphones fed by a transistor amplifier. Then they heard the first public demonstration of a fully transistor radio tuned to local stations.

Bell's press release simply stated: *"An amazingly simple device, capable of performing efficiently nearly all the functions of an ordinary vacuum tube, was demonstrated for the first time yesterday at Bell Telephone Laboratories where it was invented."*

Then Bell attended to the scientific and industrial communities. In the week prior Shockley at Bell had arranged for the publication of three short papers in the July edition of Physical Review of which the first The Transistor, A Semiconductor Triode, described the basic construction and performance of the device. [Bardeen 1948]

The following week Bell sent out hundreds of letters to manufacturers, research laboratories and the technical press inviting them to attend a seminar on the 20th July. [Riordan 1997]

At Raytheon Bell's letter dated 9 July 1948 was addressed to Laurence K. Marshall, then president of Raytheon, inviting him to Bell's Murray Hill NJ laboratory to see a demonstration of *"a new device called a Transistor."* [Goldstein 2003]

Marshall took Norman Krim to the Bell presentation and both were inspired by what they saw. [Earls 2005] *"On their return Krim prepared a report predicting that tubes would become obsolete. That was somewhat sweeping, but it was a moment of high excitement. He suggested a crash program to produce germanium semiconductors for use in the hearing aid industry."* [Scott 1974 Citing Krim] Krim had developed the Raytheon line of miniature tubes in 1938 and the company was successfully selling them for hearing aids. Here was the perfect application for the new transistor: Needing only three transistors their likely high cost was not an issue. And it was immediately clear that the transistor was a major breakthrough that would reduce battery costs and weight.



Raytheon were in mixed company. Braun and MacDonald comment *"Even the technical journals mostly managed to control their enthusiasm, many waiting until late 1948 to report the event, some until 1949, and some not bothering at all. This seems strange considering the excitement of the transistor's inventors but the explanation is probably two fold. At the time of the announcement, the transistor was little more than a laboratory curiosity. It was to become years before the device was made to do something useful."* [Braun 1982]

Electronics magazine made it their cover story in their September edition with the headline *"The Crystal Triode: Revolutionary Amplifier."*

And yet the vision was limited to replacing tubes and where better to replace them but in small portable appliances where even miniature tubes caused excessive drain on lightweight batteries.

Point Contact Diodes

"In 1948 after Laurence K Marshall then CEO and President of Raytheon and I went to the Bell Laboratories announcement meeting on transistors, I decided to go into semiconductors to protect our multi-million dollar subminiature tube sales (very profitable) and earned me Assistant Vice President in February 1948. I went into diodes in 1948 to learn the semiconductor technology and hired Lowell Pelfrey from Sylvania for his semiconductor "know how" to help Raytheon get into semiconductors. Raytheon 15+ member Sales and Sales Engineering departments sold these along with our receiving tubes and TV (cathode ray) picture tubes to TV manufacturers very early, and got up to 20 - 30,000 per day in 1949." [Krim 2009]

By the end of 1950 production was running at around a million units pa. Raytheon was a major producer, second to Sylvania which was first to market a commercial point contact diode (the 1N34 in 1946). The Raytheon semiconductor range in 1950 is given in a four page data sheet entitled "Tube Characteristics." Semiconductors were a minor part of the range at that time. In relation to its diodes the data sheet advised "In the field of Germanium Diodes, Raytheon has produced and made commercially available a line of units designed for operation up to 1000 megacycles. These Raytheon Germanium Diodes are the smallest units on the market and are rated for operation under severe conditions of high temperature and humidity."

TRANSISTORS

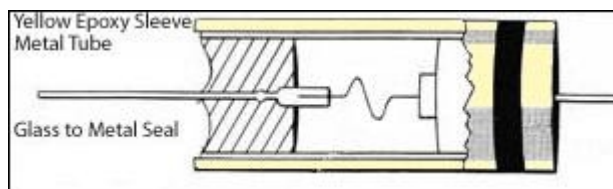
TYPE	CONSTRUCTION	APPLICATION	BAS- ING	MAX. DIMENSIONS Inches		COLLECTOR VOLTS	EMITTER VOLTS	COLLECTOR CURR. ma.	EMITTER CURR. ma.	TRANS- CON- DUCTANCE μ mhos	CO IM
				Height	Diam.						
CK703	Crystal Triode	AF-RF Amplifier	5N	0.78	.255	-30	0.2	2	0.75	5000	

GERMANIUM CRYSTAL DIODES

TYPE	APPLICATION	TERM. CONN.	DIMENSIONS Inches			MAX. DC INVERSE VOLTAGE	MAX. PEAK ANODE CURR. ma.	MAX. AVERAGE DC ANODE CURR. ma.	MIN. FORWARD CURRENT AT +1 VOLT ma.	MAX. INVERSE CURRENT AT -5 VOLTS ma.	MAX. INVERSE CURRENT AT -10 Volts ma.	MAX. INVERSE CURRENT AT -50 Volts ma.	MAX. INVERSE CURRENT AT -100 Volts ma.	MIN INVE VOLT FOR 1 DYNA RES
			Max. Length	Max. Diam.	Min. Lead Length									
CK705	Gen. Purpose Diode	7CC	0.400	0.175	1	60	150	50	5.0		0.05	0.8		1
CK706	Video Detector	7CC	0.400	0.175	1	RF efficiency at 60 MC is approx. 50%.						0.20		5
CK707	50V DC Restorer	7CC	0.400	0.175	1	80	100	35	4.0	0.005		0.05		10
CK708	100V DC Restorer	7CC	0.400	0.175	1	100	100	35	3.0				0.625	12
CK709	4 Matched Diodes	8L	2 3/4	1 1/2	Octal Base	60	150	50		Matched within 2.5% at +1 Volt.				
CK710	UHF Converter	7CC				Data will be available later in 1950.								
1N66	Gen. Purpose Diode	7CC	0.400	0.175	1	60	150	50	5.0		0.05	0.8		1
1N67	50V DC Restorer	7CC	0.400	0.175	1	80	100	35	4.0	0.005		0.05		10
1N68	100V DC Restorer	7CC	0.400	0.175	1	100	100	35	3.0					12

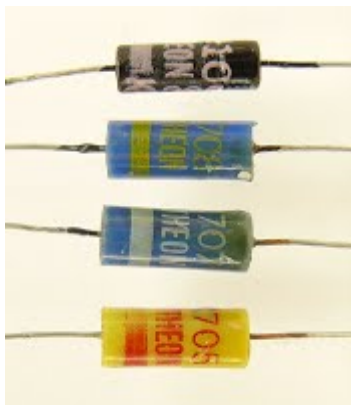
The 1N66, 1N67, and 1N68 are sealed to withstand severe humidity conditions. Data available on request.

[Data sheet courtesy of Jack Ward]



Raytheon's most common diode was the CK705 which was sold as a direct competitor to the Sylvania 1N34. The diodes were encapsulated in a metal tube with a dumet wire lead carrying the whisker insulated by a glass seal.

Early production units were affected by moisture which degraded performance. [Ward 2008]



Despite this Raytheon asserted "*more dependable performance*" in their advertising claiming seven features including the glass to metal seal at the anode end and "superior" humidity characteristics.

Early on Raytheon set an agenda for colourful packages as this set from 1952 indicates (CK705, CK707, CK708 and CK710). The colored sleeve insulated the metal body.

Encapsulation was changed in later production: the new narrower shorter tube was dipped in red epoxy as shown in these examples of CK705s from 1952 (yellow) and 1954 (red). Early on Raytheon signaled its intention to be a mainstream player and obtained RTMA registration on April 18th 1951 for its first three diodes. [RTMA 1951]



These were:

Type	PIV	I max Av	Cathode Band Colour	CK Type
1N66	60V	50ma	Red	CK705
1N67	80V	35 ma	White	
1N68	100V	35 ma	Black	CK708

Despite the early date of registration, Raytheon continued to use its CK numbering through to the mid 1950s. Around 1955 it developed and registered (1956) an extended range in the new epoxy dipped outline. [JEDEC 1956]

Type	PIV	I max Av	Cathode Band Colour	CK Type
1N294	60V	50ma	White	CK705
1N297	80V	35 ma	White	CK707
1N298	70V	50 ma	White	CK713A

Point-Contact Transistors



By the time Electronics Magazine published its September article on the new Crystal Triode Norman Krim and his team were well on the way to prototyping their first transistor: the CK703. *"In order to do it Krim had purchased diodes from Sylvania for their germanium content..."* [Scott 1974 Citing Krim] George Freedman, a metallurgist that had worked for Raytheon since 1946 was sent to Bell to learn how to produce point-contact transistors. He recalls with some pride meeting William Shockley. [Ward 2001 Photo courtesy of Andrew Wylie]

The first provisional data sheet is dated November 3 1948 only five months after the Bell announcement reflecting the company's ability to mount an urgent development programme reminiscent of the War years. [Raytheon 1948]

But in common with all early point-contact transistors this was not a robust device and Krim, retrospectively discussing the issues in 2003, noted it had to be *"handmade with watchmaker precision, which precluded cost-effective mass production. And they were none too robust. The slightest shock could ruin them, which made them useless for hearing aids and just about everything else."* [Goldstein H 2003]

The first advertisement for this transistor was in the Radio Master Catalog 15th edition for 1950-51 where the price was listed at \$18.00. [McGarrah] The first reference to the CK703 in the literature was in the January 1950 edition of Radio & Television News which gave building instructions by Rufus Turner for a crystal set with a 3 transistor amplifier based on CK703s. This was a curiosity and would have cost over \$60 in parts. By comparison the same magazine advertised an 8 tube AM-FM chassis for \$32.95! A further article by Rufus Turner published in the *Theory and Engineering* section of the June 1950 edition of Radio Electronics magazine discussed eight experimental CK703 circuits.

In 1948 Bell had filed patents on the point-contact and junction transistor and had invented the name "transistor" but its licensing programme did not begin until 1952. Early on some companies exercised caution on the use of what could have been a trade-name and called their devices "Crystal Triodes." Raytheon's provisional data sheet uses this description although the above example is emblazoned "Transistor."



The CK716 was introduced in 1952 and had the same outline as the CK703. It was intended to be more rugged and had a shock test specification of 900g. [Raytheon 1952] In fact this is not rugged at all. For example, Bell stated in an internal memorandum that its prototype transistors could withstand shocks of 20,000g. [Powers 1951]

Raytheon advertising for the launch reminded readers of the pedigree of its transistors: *"In 1948 the Raytheon point-contact transistor is perfected and put into production, now superseded by the improved type, CK716, currently available."*

Junction Transistors

Although Shockley invented the junction transistor concept in 1948 [Shockley 1948] it remained a curiosity until 1951. In April 1950 the first grown junction transistor was made by the double doping method invented at Bell. *"This non-photogenic device did perform according to theory but had a wide base, and poor frequency response and provoked little interest. For about nine months, the efforts to improve junction transistors were practically negligible at the Laboratories."* [Shockley 1976] But Shockley was confronted by the Korean War and saw that junction transistors could be used in proximity fuses for mortar shells where miniature tubes were too bulky. Work was resumed on its double doping technology and approaches to reduce the base width of the transistors made this way. [Riordan 1997]

In the Spring of 1951 Shockley was ready to tell the World that usable junction transistors had been made and was working on a paper for Physical Review ultimately submitted in May and published in July that year. The improved transistors gave higher gains with less noise than point-contact transistors and were *"exceptionally good low power amplifiers"* that would also deliver output powers of several hundred milliwatts if needed. [Shockley 1951]

Norman Krim recalls rooming with Shockley while he worked on the paper. Both men were serving on a military procurement advisory board known as the Baker Committee that needed advice on military electronics. *"Shockley would be proofreading a paper after dinner every night. He told me, 'I'm going to publish an article in the Physical Review, and you should remember, pick up that article.' When I got a copy of his article on junction transistors, that was it for me. The light bulb went on."* [Goldstein 2003]

But there was a shock in store for Bell: they were gazumped by General Electric who produced a better prototype junction transistor than Bell: the alloy junction transistor. Both Bell and General Electric presented their work at the IRE Electron Devices closed conference at Durham in June 1951 and put the semiconductor industry on notice that there were now two approaches to a viable junction transistor. General Electric's technology looked the best bet: they could demonstrate high frequency performance, voltages to 150v and large area versions could dissipate 8 watts. [Saby 1952]

The General Electric alloy junction transistor was produced by alloying tiny dots of indium metal on either side of a thin N-type germanium wafer. On heating and alloying the indium formed a P-type germanium layer under each dot. This created a PNP junction transistor. Leads were connected to the wafer (base) and the indium dots (collector and emitter) and the entire assembly encapsulated for protection. [Saby 1952]

Thus Krim decided that Raytheon would make alloy junction transistors. Raytheon knew the hearing aid market very well and transistors were ideally suited for this application: They would first target the hearing aid market.

Licensing

Bell had a pioneering position on both the point-contact transistor and the junction transistor and anyone producing either would infringe its patents. Additionally General Electric had patented its method for producing alloy junction transistors. In order for Raytheon to make alloy junction transistors it needed a license to both Bell's and General Electric's transistor patents.

Comprehensive licensing arrangements between electronic companies were common in the USA since General Electric and Westinghouse made RCA their exclusive marketing channel for receivers and tubes in return for cross licenses to their patents in 1919. Federal Anti-trust legislation both encouraged pooling of technologies while challenging any trend towards monopolies. Companies commonly swapped rights to substantial patent estates for little or no royalty.

[Tilton 1971] For example, Raytheon had such a deal with RCA as Ivan Getting, head of research at Raytheon recalls:

"Every year I had to sit down with the RCA top people and negotiate how much we owed them, and how much they owed us for their using our patents. We would host them at a dinner downtown, at a restaurant, which was famous in Boston (Lockober). After a few drinks, a good meal, a few more drinks, I would say, 'Well, it's obvious that we can't go through your ten thousand patents and claims, and that you can't go through our one thousand patents and claims that you may or may not be using, so why don't we just negotiate a settlement?' And they'd say, 'What do you suggest?' Since I knew what we had been doing, I'd say, 'We'll pay you two million dollars, and you give us a license to use all your patents, and we'll give you a license to use all our patents, but you're not allowed to sell them to others. You have to go back to direct source.' One more drink, and they'd say okay and we'd sign a document." [Nebeker 1995]

General Electric License

The outcome from Durham was a strong consensus amongst attendees that the alloy junction technology was the preferred approach. For example, RCA dropped its work on point-contact transistors and began an alloy junction programme. General Electric started licensing out its know-how. This started with its affiliates such as the British Thompson Houston Company and Compagnie Francaise Thompson Houston.

Norman Krim recalls that he *"negotiated getting a license from General Electric to make germanium alloy transistors in the summer of 1951 by approaching Raytheon President, Mr Charles Adams, whose father was then on the Board of Directors of General Electric. Mr. Adams, Dr. Getting and Dr. Bowles, a consultant and I all flew to Clyde, NY outside of Syracuse to see their experimental germanium alloy transistor live in mid-summer 1951."* [Krim 2009]

George Freedman recalls: *"Krim then made a deal with GE in Auburn New York. He gave up some Raytheon knowhow in return for allowing a delegation, of which I was one, to learn how to make alloy junction transistors."* [Ward 2001]

Adam Sheckler of General Electric confirms this writing *"An odd exchange occurred when management told us to teach Raytheon the art. This was an exchange of information. Management valued our semiconductor so poorly that they exchanged it for some radar data. It is interesting that when Raytheon was asked about 'their invention of the transistor' (about 1998) they responded 'we didn't invent it, GE taught us the art.'"* [Sheckler 2004]

Bell Laboratories License

Western Electric began offering licenses to the Bell Laboratories transistor patents after the Shockley junction transistor patent issued in September 1951. By agreement with the Military, these were restricted to NATO countries. Licensees paid a \$25,000 upfront fee deductible against future royalties and were entitled to attend the third symposium in April 1952.

"Bell had waived all license fees for the first commercial transistor product. As a memorial to Alexander Graham Bell and to his interest in the deaf, Bell did not require royalties on transistors produced for hearing aids after 1954."

"Most companies at the first Bell commercial transistor symposium eventually produced their own transistors under license from Bell. Other companies cared less for protocol and secured their transistor knowledge from RCA with whom Bell had a very comprehensive cross-licensing arrangement which included the transistor. There were still other companies which manufactured transistors for many years without benefit of anyone's training or license." [Braun and Macdonald 1982]

In 1948 Bell had supported the Raytheon point-contact programme by hosting George Freedman so it had at least an informal license. What is documented is that Raytheon had a license to the Bell transistor patents after September 1951 and attended the April 1952 symposium along with 24 other manufacturers. The Raytheon team of four was led by George Freedman. [Ward 2001] Participants received a two volume reference set entitled "Transistor Technology" that comprehensively set out practical information that would assist the new licensees set up production. It became known as Ma Bell's Cookbook. [Bell 1952]

Raytheon's First Junction Transistor: CK718

Armed with the Bell licenses, Ma Bell's Cookbook and the licenses and technology transfer package from General Electric, Raytheon was ready to begin development of its first commercial junction transistor. *"Two million dollars were set aside for the effort. That was a large sum for Raytheon at the time, and a clear indication of the importance attached to the project."* [Scott 1974]

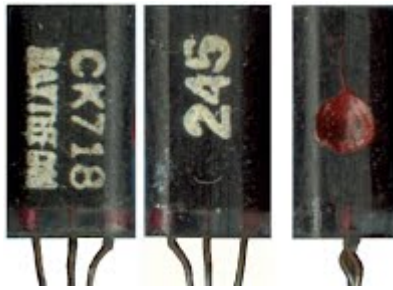
Adams, then the President of the company recruited Dr Ivan Getting. His background was military research including the Radiation Laboratory at MIT and the Pentagon. Getting was made VP Engineering and Research and commenced with the company in August 1951. A new Research Division and semiconductors were important priorities. He was unimpressed with what he found: *"In the fall of 1951 the status of transistor work at Raytheon was pitiful. One engineer, in the basement of an old red brick factory in Watertown, was melting germanium in a crucible, solidifying the melt into a heterogeneous mess of crystals and building point-contact devices, some of which showed amplification. The work was not scientific; there was no metallurgist or physicist involved. It was clear that Raytheon had its work cut out."*

A new building was leased and new hires made. Walter Leverton was put in charge of transistor research in the Research Division and in the Receiving Tube Division Krim appointed George Freedman to head a dedicated semiconductor team located at Raytheon's Chapel Street building. Soon junction transistors were being produced in both divisions. Raytheon successfully bid on a Signal Corps and Navy research contracts to improve transistor production processes *"and between these and the Company research money a substantial program was underway by 13 May 1952."* [Getting 1989]

The Research Division focussed on silicon transistors while the Receiving Tube Division developed germanium transistors for the hearing aid market.

Additional staff were appointed to work on germanium. Surprisingly Dr Charles Smith, one of the company founders and inventor of its first tube, joined the team. [Scott 1974] Others on the team were Herbert Starke and Lowell Pelfrey who had been responsible for the diode line. [Ward 2001]

The CK718 was launched as a transistor for hearing aids in September 1952 [Raytheon 1953]. Norman Krim who had worked with the hearing aid industry from 1938 headed the promotion of the new transistor. Samples were provided and sufficient demand established to launch production late 1952. In this early example the collector is indicated by a paint-filled drilled dimple. [Photo courtesy Terry Hosking]



News carried in the New York Times for January 26, 1953 reported that shipments of transistors had begun to more than fifteen manufacturers of hearing aids.

"But as Raytheon prepared to introduce its germanium junction transistor, dubbed the CK718, yields stayed stubbornly low. Water vapour and other environmental contamination occurring during the manufacturing process were to blame. To get around the problem, Krim's team used infant incubators as "clean boxes," so technicians wearing rubber gloves could reach in and assemble transistors while minimizing exposure to ambient conditions. Yields went up, and by the end of 1952, Raytheon released 10,000 CK718s to its commercial customers, the hearing-aid manufacturers." [Goldstein 2003]

Writing to Jack Ward, Norman Krim confirms the comments about complaints from early customers. *"It is correct that G E Gustafson VP Engineering Zenith called me soon after Feb 1953 and told me that a few of their transistorized hearing aids were failing in Texas, on the Gulf and Mexican borders. We immediately tested our transistors under very high humidity and found a few failing due to moisture getting in through our plastic moulded case and reaching the junction. We soon rectified the problem."* [Ward 1998] Frank Ducat, Transistor Application Engineering Manager at the time recalls these issues and considered it less of a problem: *"Moisture never did penetrate our plastic packaging. But I recall that when the story arose about this problem I stuck some CK718 in a money vest around my body inside my clothes and wore it for a month! Nothing happened."* [Ward 1997]

In 1954 Ducat published an analysis of field failures which showed that Raytheon transistors were more reliable than tubes. It did admit to an issue with open connections which had already been addressed but the data presented showed that transistors were twice as reliable as miniature tubes. The data was used to justify plastic encapsulation although within a year Raytheon had moved at least some of its production to hermetic sealing. [Dukat 1954 courtesy Jack Ward]

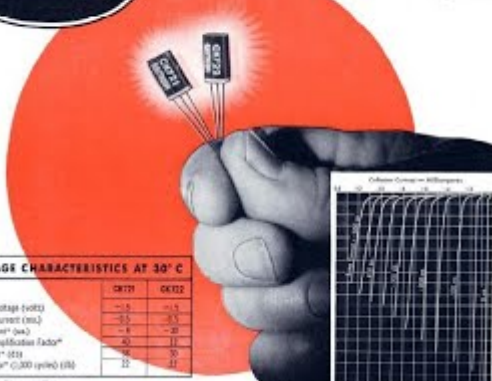
The first CK718 were mounted on a glass stem. The active elements were protected with a wax coating prior to encapsulation in a black epoxy moulding. The tradition of packaging the transistors in tube style boxes of the kind used for the point-contact transistors continued. The CK718 continued until 1955 when it became obsolete on the introduction of Raytheon's blue metal encapsulated transistors. Even then it survived on the surplus market being advertised at disposal prices as late as 1957. [McGarrah]

CK721 and CK722

Krim had been an enthusiastic hobbyist building a mechanical television set as a youth in the 1920s. Surely, he thought, there was a demand for transistors from electronic enthusiasts keen to experiment with their first transistor. *"I thought, jeez, wouldn't these rejects make a hell of a good thing? So when the guys wanted to break them up, I said, you can't do that—they're worth something. I loved to build experimental stuff and I just wanted the kids to have these. And nobody had ever seen a transistor."* Virtually as soon as production of the CK718 began, late in 1952, Raytheon began labelling low gain CK718s as CK722. In order to promote them Krim invited the major electronics publishers to Raytheon to see the new CK722 demonstrated in February 1953. [Goldstein 2003]

NOW AVAILABLE!
PNP GERMANIUM JUNCTION

RAYTHEON TRANSISTORS



	CK721	CK722
Collector Voltage (volts)	-15	-15
Collector Current (ma)	25	25
Base Current (ma)	-4	-25
Current Amplification Factor*	40	12
Power Gain* (dB)	38	30
Noise Factor* (100 cycles/Hz)	21	21

*Specified under conditions.

For the first time in history, Germanium Junction Transistors are commercially available. Raytheon Junction Transistors, types CK721 and CK722 can now be obtained for your experimental and developmental use.

Here's another first for Raytheon! Leaders in the development and production of Electron Tubes and Germanium Products, Raytheon now leads the way in production of this important new electronic development.

For price and delivery information of Raytheon Germanium Junction Transistors, write, phone or wire your Raytheon Tube distributor.

RAYTHEON RAYTHEON MANUFACTURING CO.
Receiving Tube Division
Cambridge, Massachusetts • Chicago, Illinois • Denver, Colorado • Los Angeles, California
RADIATION MONITORING DIVISION • RAYTHEON ELECTRONIC TUBE DIVISION • RAYTHEON TUBE DIVISION • RAYTHEON TUBE DIVISION

February, 1953 Radio & Television News Magazine 19

Raytheon released the CK722 and the higher specification CK721 in 1953. This advertisement appeared in Radio Television News for February 1953.

Frank Ducat of Raytheon published an article in Radio Electronics Engineering magazine for September 1953 which dealt with the variability in production of transistors, how transistors were graded after manufacture, stabilisation and strategies applications engineers could adopt to reduce the effects of transistor variability in the performance of their circuits.

"Two Raytheon junction types are now available to the military and general trade: the CK721, which can be considered a relatively high grade unit; and the CK722, a medium grade unit which is useful in many applications. The basic difference between the CK721 and the CK722 is one of current amplification, the CK721 having an alpha of about 0.95 or greater while the alpha of the CK722 runs from about 0.85 to 0.95." [Ducat 1953 cited by McGarrah] The above advertisement set out the basic parameters for these transistors indicating an h_{fe} of 40 and 12 and a power gain of 38dB and 30dB for the CK721 and CK722 respectively.



In fact all CK718, CK721 and CK722 came from the same production run. Frank Ducat confirmed: *"The highest quality transistors were labelled CK718 and were set aside for hearing aid use. The CK721's were selected next from those units which had a high enough current gain. The CK722 was what was left after all the other selections had been made."* [McGarrah 1999]

The issue of quality control persisted throughout Raytheon's brief history of transistor production. In an oral history for Jack Ward Ducat recalls that at the Lewiston plant they sorted transistors by gain and voltage breakdown into 200 lots from which customer orders were despatched. [Ward 2001]

"Even after 10 to 12 years the alloy process was still not very well controlled. Fortunately the bulk of Raytheon transistor production was used for computer switches whose specifications were easily met. What was left over went mainly into portable radios. Raytheon's largest customer was General Electric."
[McGarrah 1999 Photo courtesy of Bob McGarrah]

Early Dominance

The April 1953 edition of Raytheon News reported that the company was the World's largest producer of transistors making tens of thousands per month. It quoted Fortune Magazine (March 1953).

"Fortune Magazine calls 1953 the year of the transistor. In its March issue, Fortune told how the transistor "the pea size time bomb" is revolutionising the electronics industry. Since the beginning of the year when mass production of transistors got underway, Raytheon is leading as the biggest producer of junction transistors. Production of transistors at Raytheon is at the rate of tens of thousands per month.

"In the transistor," Fortune said, "man may hope to find a brain to match atomic energy's muscles." One of electronic's wonder devices, transistors free devices from the limitations of vacuum tubes by providing compactness and low power consumption.

The first small commercial returns of transistors are coming in from the immediate practical application of the hearing aid trade. Over ten concerns are now manufacturing tubeless hearing aids using three Raytheon junction transistors." [Reproduced in Earls 2005]

Millionth Transistor



On June 23rd 1954 Raytheon produced its millionth transistor and issued souvenir paper weights in celebration of this milestone. Company President, Charles Adams presented a mounted gold plated transistor to the State Governor, Christian Herter who noted for the occasion *"I am sure that this achievement is made possible by the emphasis placed by Raytheon on research and development. Massachusetts is very proud of its leadership in the scientific world. Raytheon is to be congratulated also for its Yankee ingenuity and drive which made it possible to convert these scientific researches into real production."* [Raytheon News August 1954 reproduced in Earls 2005 Picture courtesy Jack ward from Tele-Tech & Electronic Industries]

At the same function a seven transistor portable radio was presented (seen in the bottom of the background to this picture).

Hearing Aids

Hearing aids were the first consumer device to make use of transistors, which quickly replaced miniature tubes made by companies such as Raytheon and Sylvania. The first hearing aid to use a transistor was the Sonotone 1010 model from 1952. It had two tubes in the preamplifier and one transistor in its output stage sourced either from Germanium Products or Radio Receptor.

Maico were the first to produce an all transistor hearing aid (the Transit-ear) late in 1952 using three Raytheon CK718 transistors and powered by a single 1.5 volt cell. Due to the variability of their manufacture Maico had to customise the biasing of each transistor. [Armstrong 1953 reproduced by McGarrah]

Zenith also introduced a transistor hearing aid in 1953 (the Royal T) pre-selecting and colour coding its CK718s to suit each of three stages. They had trouble with Raytheon transistors and actually suspended production while failure problems attributed to moisture ingress were investigated. [Ward 1998]

By March 1953 *"over fifteen hearing-aid manufacturers were buying Raytheon transistors. Thus, only eighteen months after the junction transistor was announced, it was beginning to supplant vacuum tubes that had enjoyed forty-five years of steady refinement. To be sure, the transistors used in hearing aids cost perhaps \$5 to \$8 each, as against \$1 to \$1.60 for a subminiature tube, but the game is still young. "We expect," says Germanium Products, "to chase the vacuum tube price to hell and gone."* [Fortune Magazine 1953 cited by McGarrah]

By 1954 hearing aid manufacturers had virtually completely switched to transistors. Raytheon had the largest market share.

Research and Development

Although Raytheon held a license from General Electric for the alloy junction transistor it needed to develop manufacturing processes since General Electric did not commercialise its own alloy junction transistors until September 1953 when it launched the 2N43-45 series in its familiar hermetically sealed evacuated can.

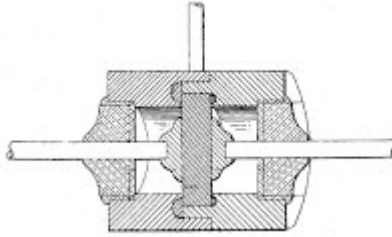
Raytheon was faster to market by a year largely because it used cruder manufacturing methods such as resin encapsulation.

Raytheon received Federal funding from 1952 to assist it develop manufacturing processes. Known as Production Engineering Measures (PEM) companies such as Western Electric, General Electric, Sylvania and Raytheon received funding from the Signal Corps in return for a commitment to develop production capacity for 3000 transistors a month. [Melliard-Smith 1998] One such example in the case of Raytheon was a contract to develop a silicon transistor. [Ward 2001]



Raytheon used the letters "QC" over the early to mid 1950s to designate development types as shown in this montage of photos including a QC103, a

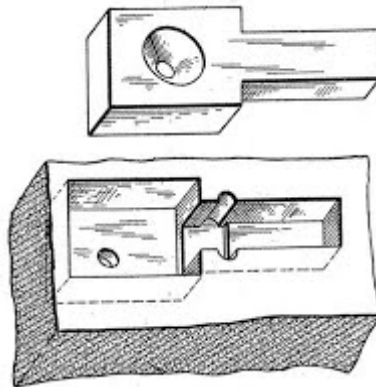
QC117 and a QC143A. [Photo courtesy of Joe Knight] Later the letters "DEV" were also used.



This configuration was used by Hughes Aircraft for some of their point-contact transistors.

Raytheon patented the process improvements it made where it could including inventions that it did not commercialise. An example of one approach patented in 1952 that it did not explore was a compact axial transistor more in the style of crystal diodes being sold at the time. [Blais 1952]

Improved Manufacturing

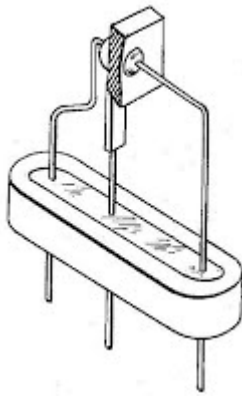


Raytheon needed methods to better automate production and filed two patents on multiple well graphite jigs to hold all the internal parts of a transistor in place prior to alloying (the indium dots, base tab and germanium wafer). The parts were assembled by putting the first indium dot in the bottom well, followed by the wafer, the base tab and the graphite top plate. The second indium dot placed within the well in the insert. [Williams 1953]

Methods of encapsulation were patented. Irving Levy patented a method of welding a metal case to a metal tube holding the stem and transistor assembly under an inert gas. [Levy 1953] John Sardella patented a method of encapsulation using fluorocarbon polymers that had high moisture resistance and that were moulded into a screw on cap. [Sardella 1953] and a further method of resin encapsulation in which the active elements of the transistor were first protected with a blob of polyethylene and then forced into a metal case filled with a casting resin using a cold set adhesive to seal the stem insulator to the metal case. [Sardella 1955] The idea of using protective plastic around the transistor elements was applied in Raytheon's hermetic sealing process.

Hermetic Sealing

Raytheon introduced an improved hermetically sealed metal can to replace resin encapsulation. The first such transistors were the 2N63, 2N64 and 2N65 series from 1954. They were clones of the CK722, CK721 and CK725 still being produced in their black resin outline. [Raytheon 1954] The new stem assembly consisted of a glass insert sealed into a tinned metal jacket. Prior to sealing the transistor was encapsulated in "special plastic." [Raytheon 1957] The can was soldered to the stem



under an inert atmosphere to avoid contamination of the semiconductor surface. Tinning avoided the need for fluxes on final assembly also reducing the risk of contamination. [Parziale 1956]

On introduction of the new can, Raytheon began to use its distinctive sapphire blue paint on its germanium units which it continued through to the late 1950s. At the same time it began obtaining JEDEC registration of its transistors and used 2N type numbers

in parallel with the CK numbering series.



The oval outline shown above was hermitically sealed. Other metal cased transistors were resin encapsulated.

New AF Transistors

As part of the hermetically sealed range of Raytheon Blues a new audio frequency range was released by Raytheon in 1954-1955. These are indicated in the table:

Type		h_{fe}	Gain	Noise
2N63	AF Amplifier	22	39 dB	25 dB
2N64	AF Amplifier	45	41 dB	22 dB
2N65	AF Amplifier	90	42 dB	20 dB
2N106	Low Noise	25	36 dB	12 dB

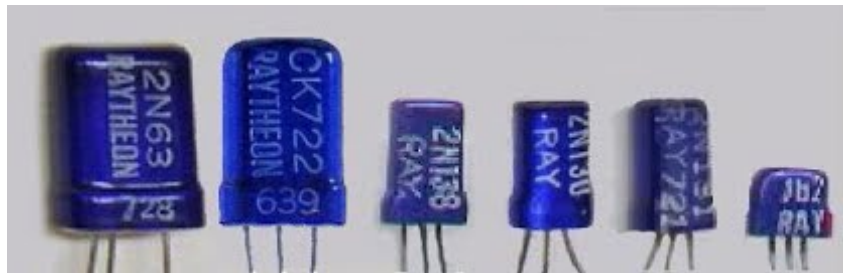
1955 was a watershed year for Raytheon with respect to new package outlines. Late in 1955 it introduced its 2N130-133 and CK782-CK785 series in a miniature outline. These were intended for use in hearing aids such as the Maico Transit-ear from 1955. Curiously this hearing aid uses other standard sized components therefore not fully realising the benefits of the miniature transistors.

Link to <http://transistorhistory.50webs.com/maico55.html> Bob McGarrah

In addition, Raytheon produced half height miniature types which carried an "A" suffix. These transistors are all functional equivalents in different outlines

Oval Outline *	Rectangular Outline	Miniature Outline	Subminiature Outline
2N63	CK722	2N130	2N130A
2N64	CK721	2N131	2N131A
2N65	CK725	2N132	2N132A

2N106	CK727	2N133	2N133A
* Hermetically sealed			



Raytheon Blue outline styles were introduced in 1955. [Photos of the 2N138 and CK722 courtesy Bob McGarrah]

The CK722 was issued in the new sapphire livery but continued the tradition of utilising off specification hearing aid transistors. These were now miniature types a fraction of the size of the original CK718. Those rejected for hearing aids were simply encapsulated in a can that preserved the dimensions of the old black resin case. [Ward 2003]



Despite the deliberate branding through the use of blue paint, Raytheon did not standardise the colour and like natural sapphires, these transistors can be found in a range of distinctively different blues. [Photo courtesy of Joe Knight] The CK726 is a semi-miniature type for hearing aids.

For further information, see Jack Ward's comprehensive photo-essay on the [Raytheon Blues](#)

2N272 and 2N273 Double Encapsulation

The 2N272 was issued in 1958 in Raytheon's standard oval outline intended as a driver for medium power audio amplifiers. The 2N273 was intended for Class B outputs and was sorted and matched for gain in five groups.

Both are of interest because they continue the practise at Raytheon of potting smaller transistors in a larger outline. This strongly suggests that Raytheon had a significant surplus of AF hearing aid transistors that did not meet specification something Frank Ducat confirmed for Bob McGarrah referring to Raytheon's approach to grading transistor output: *"Even after 10 to 12 years the alloy process was still not very well controlled."* [McGarrah 1999]

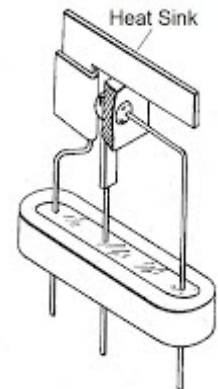
Improved Power Transistors



Early efforts to make a power transistor utilised a metal tab to give improved heat transfer from the transistor overcoming the adverse insulation effects of the early resin encapsulation. A development type (QC113) is shown here [courtesy of Joe Knight] which became the CK750 (below showing production from the end of 1955).



These transistors were not successful as the metal tab permitted increased ingress of moisture, something that was already problematic in Raytheon's resin encapsulated transistors. *"A good plastic to metal seal is difficult to realize, and even if attained, is subject to deterioration with extended use..."* [Parziale 1956] The introduction of metal cases around 1955 created the opportunity to improve heat transfer by soldering a metal tab to the emitter dot which, on final assembly, was soldered to the top of the can creating a large area heat sink that improved cooling.



Given the issues of sealing the metal tab in the CK750, Raytheon introduced the CK751 which was in a sealed metal case with a fitted external fin that enabled it to be bolted to a metal chassis. It was specified by Olympic for their four transistor portable, the Olympic 447, as a class A audio output transistor and some Emerson 868 sets when they utilised Raytheon transistors.



This is a rare transistor. This example shown is date coded for 1956. [Photo courtesy of Joe Knight] When used in Class B output stages and with the CK751 strapped to a metal chassis 500mw output was possible. The other "power transistor" available from Raytheon at the time was the 2N138A which could deliver a very modest 100mw in class B. [Raytheon 1957]

In 1957 Raytheon introduced a germanium power transistor, the CK753 in a TO-3 package. Some companies such as Clevite, Motorola and Sylvania had introduced TO-3 germanium transistors in 1956 and others such as RCA and Tung-sol



introduced germanium TO-3 power transistors in 1957. The CK753 is a rare transistor and was virtually obsolete by the time it was introduced. For example, RCA registered the 2N1490 60W silicon diffused transistor late in 1957. This evolved into the ubiquitous 2N3055. A full and comparative account of the [history of power transistors](#) has been written by Joe Knight [Photo courtesy Terry Hosking]

Transistor to Spacistor Part Two

First RF Transistors

Silicon Transistors

Junction Diodes

The Spacistor

From Transistor to Spacistor Acknowledgements

"Is it possible to love a transistor" asked Harry Goldstein in 2003. If it is then the World's most loved transistor would be the CK722: the transistor that introduced millions to the new world of semiconductor electronics in the 1950s. And not any CK722 but the mid 50s version that sported a chunky shiny sapphire blue case that said "look at me" in any circuit.

The person who has had the longest affair with the CK722 is Jack Ward who maintains a [virtual museum of transistor history](#) including a dedicated site to the CK722. This site is the leading resource for those interested in the history of semiconductors. In addition Jack Ward has published "*The Story of the CK722*" including oral histories of some associated with Raytheon and its customers comprising a further invaluable resource.

Bob McGarrah is another well known name in the field of transistor history who has a substantial archive rich in semiconductor history including comprehensive historical material on early semiconductor radios and hearing aids.

These sites are highly recommended for those that want to understand the love affair with 1950s technology. They have been a valuable source of information for this article.

The author would also like to acknowledge the considerable assistance and helpful comments of Joe Knight who seems to have an inexhaustible library of data and images covering both early tubes and semiconductors. He has published a [lengthy series on power transistors](#) including Raytheon.

What breathes life into any history are the oral histories of those who were part of it. Much of this has been recorded and archived by the IEEE History Center, Rutgers University, New Brunswick, NJ, USA. Their permission to use this material is gratefully acknowledged.

Two books have been published on Raytheon's corporate history. In 1974 Otto Scott wrote the official history of Raytheon "The Creative Ordeal" and in 2005 Alan Earls and Robert Edwards wrote "Raytheon Company; the First Sixty Years." Both these books are based on Raytheon company archives research and

interviews with many of the company's pioneers. Neither of these books feature Raytheon's semiconductor history in any significant way: they should be read for context.



Mr Norman Krim is one of the most important names in Raytheon's semiconductor history having recommended the entry of the company into that business immediately after the Bell Laboratories announcement of the transistor in 1948. On his retirement he became the Raytheon Chief Archivist leading a small group who worked to catalogue and protect the company's records.

Following the first publication of this article in 2009 he kindly reviewed it and provided further insights and commentary now included in this revised version. His contribution is gratefully acknowledged. Sadly Norman Krim died on December 14th 2011 at the age of 98. An obituary in the New York Times described him as "*an electronics visionary who played a pivotal role in the industry's transition from the bulky electron vacuum tube, which once lined the innards of radios and televisions, to the tiny, far more powerful transistor.*" Picture right courtesy of Chet Michalak.

Photo Credits: The author is grateful for permission from Joe Knight, Bob McGarrah, Terry Hosking and Andrew Wylie to use their images in this article.

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