Solar Radios, early Solar Powered Radios

(by Lello Salvatore *)

A brief history of the silicon solar cell

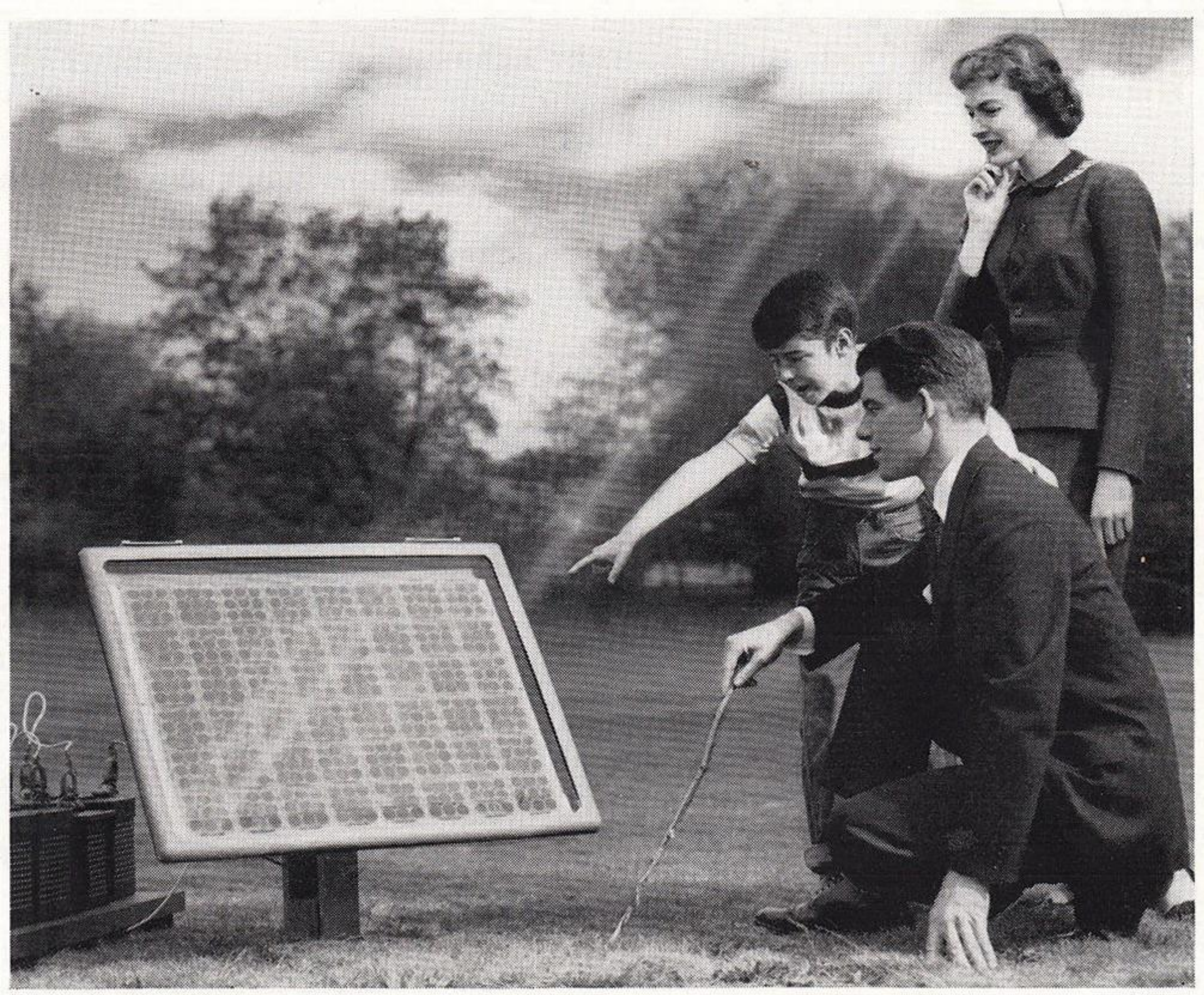

Fig.1

It was April 25, 1954, a Sunday, when Bell Telephone Laboratories (Bell Labs for short) held a press conference at their headquarters in Murray Hill, New Jersey (USA), twenty miles from New York City, to announce the invention of first silicon solar cell, called by the Laboratories themselves, "Solar Battery"as clearly reported by their first ads**:** one of theseadsappeared in No. 7/1954 of the American magazine "RADIO & TELEVISIONE NEWS"[1]while the one shown in Fig.1 (from my personal collection) can be found on page 3 of LOOK Magazine dated 08.21.1956. Some applications of the solar battery were shown to journalists and photo-video reporters: a panel of solar cells (obtained by connecting several cells in series) which, illuminated by the artificial light of a lamp, activated small electricmotors like that of a 21-inch toy Ferris wheel (about 53 cm) and that of a pinwheel. Additionally, Bell Labs engineer D.E. Thomas demonstrated how his voice could be heard clearly from a radio receiver placed on the lawn of the Murray Hill Laboratories speaking from a small radio transmitter powered solely by the sun's rays incident on the solar panel[2].
The news of the new invention had wide coverage in the newspapers, appearing on the front pages of the Wall Street Journal and the New York Times[3]which in the issue of the following day headlined"***Vast Power of the Sun IsTapped by Battery Using Sand Ingredient"***and explained that......*The experimental solar battery is a simple-looking device constructed of wafer-thin strips of silicon (the main ingredient in sand) about the size of common razor blades. These strips are extremely sensitive to light and can be connected together electrically and deliver 50 watts worth of power per 1 square yard of surface area*[4]. The article enthusiastically stated that…*with this modern version of Apollo'schariot*[5]*, Bell scientists harnessed enough of the sun's rays to power*

the transmission of voices over telephone wires to have a 6% efficiency in converting sunlight directly into electricity, " adding prophetically that,*" the solar battery could herald the beginning of a new era, eventually leading to the realization of one of mankind'smost cherished dreams**:** the harnessing of the sun's almost unlimited energy for the uses of civilization.* The demonstration of the fabulous Bell Labs solar battery also took place at the annual meeting of the National Academy of Sciences held in Whashington D.C. precisely on April 26, 1954 where Dr. William Shockley, a leading scientist of the Bells, also participated to collect the coveted Comstock prize. Shockley was author of the theory of the junction transistor published in July 1949 in the Bell System Technical Journal with the title "The Theory of P-N Junctions in Semiconductors and P-N Junction Transistors")[6]

Fig.2 (the three inventors of the solar battery)

As it had happened with the transistor, announced six years earlier in the great press conference of June 30, 1948 by Bell Laboratories themselves, this new invention also had something revolutionary in it because it wasable to generate electricity in an economical and fairly efficient way using the energy from the sun's rays. Unlike the already existing selenium solar cells (the first wasinvented in New York in 1883 by Charles Fritts!) which managed to convertbarely 1% of the incident sunlight into electricity and which for this reason had little practical applicationas, for example, in camera light meters, the new silicon solar cell from Bell Laboratories was considerably more efficient, converting up to 6% of the incident solar energy into electricity, the threshold that the inventors managed to reach, considering it necessary to use the solar battery in the new Bell transistor telephone systems.In fact, Bell Labs' interest in solar energy had be enpiqued by a practical problem Bell Labs had to solve: the rapid degradation of the traditional dry-cell batteries used in the remote, humid regions of the United States in the Bell telephone system. The task of studying other feasible power sources was given by Bell executives to the engineer Daryl M. Chapin (in the center in the photo of Fig.2) who, rejected the use of other alternative sources suchas wind machines, thermoelectricgenerators or small steam engines, and with the approval of his supervisors, from the end of February 1953 began to apply on selenium solar cells. However, when Gerald L. Person (on the left in Fig.2) hislaboratory colleague and personal friend told him not to waste any more time with selenium but to try using silicon which was demonstrating greater efficiency, Chapin did not hesitate for a moment and began to experiment with this material. Pearson had studied physics at the same university as Chapin, Willamette University in Salem (Oregon, West Coast state) and obtained a master's degree in physics at Stanford University (near Palo Alto in California) and was considered by his closest colleagues the "experimenter of experimenters". He and another scientist, Calvin S. Fuller (on the right in Fig.2), an expert in physical chemistry, inside Bell Laboratories had studied how certain impurities affect the properties of silicon and were experimenting with new diffusion techniques to improve the junction transistor which since its first practical realization, which took place with success in the laboratory by Gordon Teal and Morgan Sparks on April 12, 1950, was built using germanium and with the primordial technique of draft (or growth of a single crystal) or by the process by alloy. The three scientists worked severalmonths to improve the properties of their silicon solar cells by experimenting with various impurities including gallium and lithium before and subsequently, thanks to Chapin'sindications to create a p-n junction very close to the surface of the cell, replacing the lithium with the phosphorus obtaining decidedly better performances. Theoretical calculations brought even more encouraging news. An ideal silicon solar cell, Chapin thought, could convert 23 percent of sunlight into electricity. However, the problem still remained of making good electrical contacts on the silicon, essential for drawing on the electricity generated by the cell. The help of Fuller who had been busy in hislaboratory was decisive, together with that of Pearson, in producing more efficientcells, superior to the others that the three scientists were experimenting in their teamwork overcoming obstacles at various times seemingly insurmountable. It took more than a year, and at the beginning of 1954, starting from a thin slice (wafer) of silicon, the size of a razor blade of those old razors, and previously made negative, i.e. type N (rich in mobile negative charges, electrons) by adding arsenic atoms (pentavalent impurities), Fuller and Pearson had managed to diffuse boron impurities (trivalent) thus forming a P-type layer (rich in positive mobile charges, the holes) over the entire surface of the wafer extremely thin, less than 1/10,000 of an inch (0.1 mil = 2.54 microns, i.e. slightly greater than 2 thousandths of a millimetre). The specially created p-n junction at the optimum depth from the wafer surface excited an electric current flow in the silicon when subjected to light. The use of boron, in addition to allowing for the creation of a p-n junction very close to the surface of the silicon wafer, had also made it possible to establish good electrical contacts, allowing the useful target of 6% conversion efficiency to be achieved. Unlike Shockley, Bardeen and Brattain, the most famous trio of scientists who invented the transistor, Pearson, Chapin and Fuller did not receive the Nobel Prize, but in 2008 they were inducted into the Hall of Fame of Inventors (NIHF)[7] of United States. Their "Solar Battery" patent, applied for on March 5, 1954 under Serial No. 414,273, was titled "**Solar Energy Converting Apparatus**" and was issued on February 5, 1957 by 'United States Patent Office No. 2,780,765.[8].As mankind we can never be grateful enough to all these scientists for their brilliant work and the least we can do is remembert hem often!

Fig.3Americus (GA): First Solar Battery Installation Marker,

The first use of the new Bell invention took place in rural areas of the United States in early October 1955 when in the cotton fields of Americus, Georgia (about 135 miles south of Atlanta) (Fig.3) the battery panel, composed of 432 specially prepared silicon solar cells, filled with oil and covered with glass, was mounted on top of a telephone line pole (Fig.4)[9]. During the day the solar panel supplied power directly to the line and the excess energy was fed into a storage battery to run the line at night and in bad weather. The test gave proof of reliability and effective operation by being able to supply electric current to the very latest transistor equipment[10](Fig.5) with which the new experimental telephone lines were being equipped. However, until raw materials, technology and electrical storage became cheaper, the intensive use of solar panels in rural areas could not proceed quickly. The scientists and executives of the Bell Telephone System had immediately understood that with this new renewable source of energy they had created something greater but an industry had yet to be born. In fact, the marketing and production of the new solar cells proved to be very complex and was initiated and pursued by small companies, such as NATFAB (National Fabricated Products, 2650 West Belden Avenue, Chicago 47, Illinois), Hoffman and Spectrolab founded in 1956 by Alfred Mann.

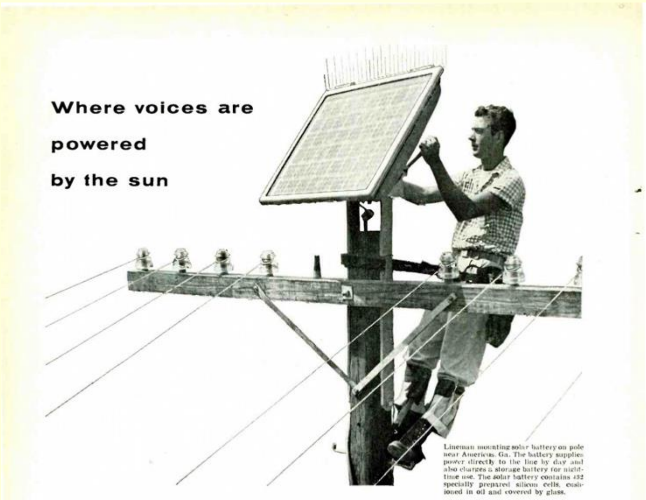

Fig.4

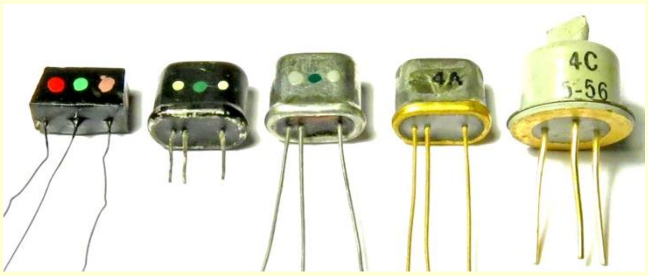

Fig.5 (the very first junction transistors for practical use)

Hoffman

On December 4, 1941, Hermann Leslie Hoffman (1906 - 06.24.1971) began his brilliant career as a courageous, shrewd and later also a philanthropist entrepreneur by taking over the nearly bankrupt Mission Bell Radio Manufacturing Company, a small Los Angeles company that manufactured small radio receivers, for $2,500. The new Hoffman company continued for a short time with the production, design and Mission Bell brand starting in 1947 with the production of its own radio models and from 1948/49 also that of televisions since RCA had made its television patents free from royalty. Hoffman Radio and Television within two years (1948-1950) had become the largest television manufacturer on the US West Coast, increasing sales from $3.5 million to nearly $12 million. Leslie Hoffman's success was in the quality of his products. Hoffman radios and televisions were built well, using proven engineering methods and some times even applying solutions used in military electronics. During the Second World War Hoffman had in fact produced electronic equipment for the military and continued to supply them in particular to the Air Force, even after the war and in the following decades. Hoffman also slowly transitioned to color television (introduced slowly in the US beginning in 1954) and by the late 1960s had a full line of consumer products. In 1953 the company changed its name to Hoffman Electronics Corporation diversifying the production which it organized into distinct divisions including that of consumer products (radio and television), semiconductor devices and military products. Leslie Hoffman, convinced that the Sun could power other products, at the end of 1954, began to produce solar cells obtaining within two years efficiencies of up to 10% from normal production cells and up to 13% from cells produced in the laboratory[11]. In 1955[12]he acquired National Fabricated Products which owned the license to the original Bell Labs solar battery patent and continued to make strides in making the solar cell a practical and useful source of affordable renewable energy. The solar panels produced by Hoffman proved to be fundamental in the nascent US space industry and were used in Vanguard 1, a small sphere of aluminum alloy (diameter 16 cm and weight of 1.47 kg), the size of a grapefruit, launched, for scientific purpose, on March 17, 1958. Vanguard 1, the first satellite in history to be powered by solar energy, a dwarf compared to modern satellites, was equipped with a pair of transmitters that sent signals around the frequency of 108 MHz using six short antennae protruding from its small body. One of these transmitters was powered by mercury batteries while the other transmitter made use of six small solar arrays (each approximately 5 square cm in area) mounted equally spaced around the spherical exterior of the satellite so that they could provide power independently of the its orientation. They had been positioned there as part of a test to determine their usefulness on future spacecraft.

Fig.6

In June of that year, the satellite's mercury batteries were completely out of order while the last signals transmitted by the transmitter equipped with silicon solar cells were received by the Minitrack receiver system in Quito, Ecuador, until May 1964, 6 years later: therefore not bad for the brand new solar panels which from then on went to power the over eight thousand artificial satellites (8,261 as of January 2021!) orbiting the Earth. Even the Explorer 6 satellite, launched on August 07, 1959, had on board an array of four solar panels (also called modules) made up of 9,600 solar cells (as reported on the web at the address: https://it.wikipedia .org/wiki/Explorer_6#/media/File:Explorer_6_paddles_up.jpg.

As for the button-shaped mercury batteries, an advertising tag attached to the packaging of one of myPhilco radios dating back to 1958, the T4-124, exalted the quality of these batteries produced by this famous American company showing the drawing of the Vanguard 1 satellite (Fig.6) next to a small and powerful mercury battery, a P630 of the type used in this satellite but also in the previous 'Explorer 1.

Solar Radios

The world's first commercially available solar-powered radio was officially announced in the columns of the Chicago Tribune on April 14, 1956 (page 37) and the first sets were sold starting in May as reported at the bottom of the same article[13].The first set was delivered personally by the executives of the manufacturer, the Admiral Corporation of Chicago, on May 10, 1956, to Eugene B. Germany, president of the Lone Star Steel company. The Admiral Corporation was an electronic company of radios, televisions and household appliances founded in Chicago in 1934 by a great entrepreneur and businessman, Ross D. Siragusa, born in Buffalo, N.Y., in 1906 of Italian parents originally from Lascari (PA).

Fig.7

It was a 6-transistor portable radio receiver operating on the Broadcast band (BC), i.e. Medium Wave, with a good audio performance and very appealing aesthetics which waspowered by 6 D-typebatteries (torch) connected in series or, in absence of batteries, exploiting the energy of the sun through the "Sun Power Pak", a solar panel composed of 32 silicon cells which was connected to the radio via a cable to be inserted into the power socket located on the back of the cabinet. The radio was available in four color variations: red, brown, yellow and turquoise identified by the models 7L12, 7L14, 7L16 and 7L18 respectively and was sold for a starting price of $59.95. The solar panel could be purchased separately (it wastherefore an option!) at the very high price of 185 dollars which, as Bill reminds us, today corresponds to just over 1,900 dollars, 10 times as much (!) while with 40 dollars he also received the special leather transport bag in which to insert both the radio and the solar battery. A very colorful ad, coming from my archive and taken from the Holiday magazine of the summer of 1956 (Fig.7) shows this new electronic marvel, the 7L series, in all its color variants. It is natural to wonder, at this point, who was the builder of the very expensive solar panel sold by Admiral -- certainlynot the same company but certainly the Hoffman seen and considered that the same produced

Fig.8 (Hoffman mod. R-P411)

solar cells and the previous year had taken over the National Fabricated Products.
Not even a year had passed since the release of the 7L series when the Hoffman Corporation, on page 27 of the Los Angeles Mirror News of January 14, 1957 (see note 13), announced the market release of its first radio powered by the rays of the sun, model P411 "SOLARADIO", "HOME ε TRAVEL ALL TRANSISTOR", retailed at an initial price of $159, including $9 for the 4 important rechargeable cells (yes rechargeable cells already in 1957!), type AA, from 1 25 volts each, designed to power the radio in the absence of light.

Fig.9 (Hoffman mod. R-P411 inside)

The particularity of this splendid and unique 6-transistor radio, also in Medium Wave (OM) only (Fig.8 and 9), was that its 5 volt total solar cells panel was not external but rather incorporated in its large carrying handle and in addition the solar cells charged the 5 volt rechargeable battery housed in the cabinet. The solar panel, no longer external or optional as in the Admiral 7L series but constituting the handle of the radio, made it a new and complete set without the need for an external "Sun Power Pack". The electric current produced by the solar panel consisting of two banks of cells reaches the radio circuit through the same heavy metal handle which is joined to the cabinet by means of two large knob-like screws which hold the two attachment ends in position (Fig. 9). It is important to note that all the electronic component sused in the P411 model were "made in the USA" (with the letter "H" drawn on the transistors) with the exception of the "Polyvaricon", the variable capacitor in plastic (solid dielectric) invented by the Japanese by Mitsumi, the volume/on-off switch and, more unique than rare, the plastic cabinet. This cabinet had in fact been supplied by Sony when it was still officiallycalled TOTSUKO (Tokyo TsushinKogyo Ltd) and that with minimal variations the same had used for its TR-6 model launched in May/June 1956. It iscurious to note that the inscription, "SONY" still appears on the support easel of the P411 model! A less expensiv eversion of this model wa salso made, selling for 79.95dollars, the P410 model, without the solar panel and with a simple rigid metal handle but identical printed circuit board (Ch.1109). Chassis 1109, i.e. the circuit of this set, was obviously different from the one used in the Sony TR-6 and if the latter model was available in four colors, both Hoffman models were made in 5 different colors indicated with one of the following letters placed before the model code (P410 or P411). Thus there was black, indicatedas K-P411 (or K-P410), desert sand identified by the letter B, turquoise (T), calico red (R) and circus pink (P). The 6 transistors used, all inserted in the appropriate sockets, are: 2N212 x 1, 2N216 x 2, 2N35 x 1, 2N228 x 2, probably supplied, according to Alan Kastner (see note at the end of the article), from Sylvania. I agree with Alan that this radio represented the culmination of revolutionary technology and design and was therefore a high-end luxury item, as evidenced by the price as well as its appearance on the cover of Popular Science magazine in August 1957.

Hoffman P706series

Fig.10 (Hoffman mod. PP 706)

The luxurious and very expensive Hoffman P411 was followed in June 1958 by the "TRANS-SOLAR", mod. P706 (Fig.10), elegant and like its older sister, highly sought-after by collectors of transistor radios.

This radio set also gets the electricity it needs from a solar panel (also called photovoltaic)[14] placed on the top of its cabinet (Fig.11) and, in the absence of light, it can be powered by an internal 4-volt, non-rechargeable mercury battery, such as Hoffman H930003 or Mallory TR233R or other equivalent types. A switch placed at the top on the back of the plastic cabinet allows you to switch from the mercury battery to the solar one. Unlike the much larger P411 model, the P706 model can be defined as a coat pocket as it has a cabinet measuring 14.5 cm (W) x 8.9 cm (H) x 4.3 cm (Prof.), more or less as big as the mod.2010, the transistor "Radialba" the Italian Allocchio Bacchini set which I remember was the first transistor radio built in Italy, having been presented in September 1956 at the National Radio and Television Exhibition (from *l'Antenna 06/1957*, page IX) .The Hoffman cabinet was made with a new highly resistant plastic material, the one that the Americans of Marbon Chemicals developed and sold under the name of cycolac, i.e. ABS (Acrylonitrile-Butadiene-Styrene). The photovoltaic panel of the "TRANS-S0LAR" has a length of 12.3 cm and a width of 3.1 cm and consists of 12 solar cells each in the shape of a quarter of a circumference (Fig.12)[15] therefore with a central angle of 90° and a radius of 1.5 cm. From a simple calculation it results that the total surface of the twelve solar cells, the one actually responsible for converting the energy of the sun's rays into electricity, is equal to 21.195 square cm. At this point it is interesting to read the general operating characteristics of the circuit of this radio set, indicated as chassis 1123, shown on the large label (Fig.13) glued to the inside of the rear panel. From it we can deduce both the voltage value, equal to 4.8 volts, that the small panel of the P706, this solar battery, has at it sends when it is exposed to full midday sunlight (maximum intensity of solar radiation), and the value, equal to about 25 milliamperes, of the current circulating in a test load applied to the ends of the small solar panel and having a resistance of 190 ohms. Electrothecnics teaches us that the product of an electric voltage (V) and a current (I) expresses a power (P) which indicates the electric energy produced in one second, equal in this case to: 4.8 25/1000 = 0.12 W, i.e. 120 milliwatts. This is a maximum theoretical value since the power required by this radio receiver is more contained which, during operation with solar power supply in the early hours of the afternoon and at a normal, average volume, has an electrical voltages lightly higher than the 4 volts while the current absorbed slightly exceeds 20 milliamperes. A video I posted on the afternoon of July 30, 2011 on my YouTube channel (TuttoTransistor) shows how it works: (https://www.youtube.com/watch?v=tayaooUZuNA). Once the solar battery has been removed, the P706 has a circuit configuration (Fig.14) typical for the time, i.e. that of a common superheterodyne equipped with 6 transistors, in which the tuned input signal (the one selected in the Medium Wave range from 535 to 1,620kc) is first converted by an oscillator-mixer transistor, a 2N252, in the intermediate frequency of 455 kc, amplified by two intermediate frequency transistors, a 2N253 and a 2N254, and then detected by a diode (1N295). The audio signal (of low frequency) obtained at the output of the detector diode is amplified in voltage by a driver transistor, a 2N238, and finally by a pair of 2N185 connected together in a push-pull circuit for power amplification. All these transistors are soldered directly on the printed circuit board (signed H560005)

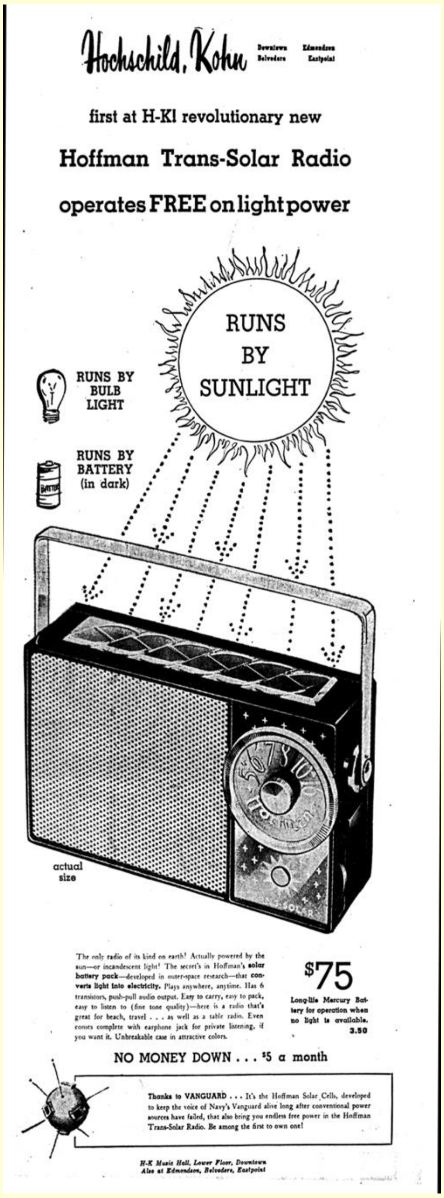

Fig.11

Fig.12 (quarter solar cell of Hoffman mod. PP 706)

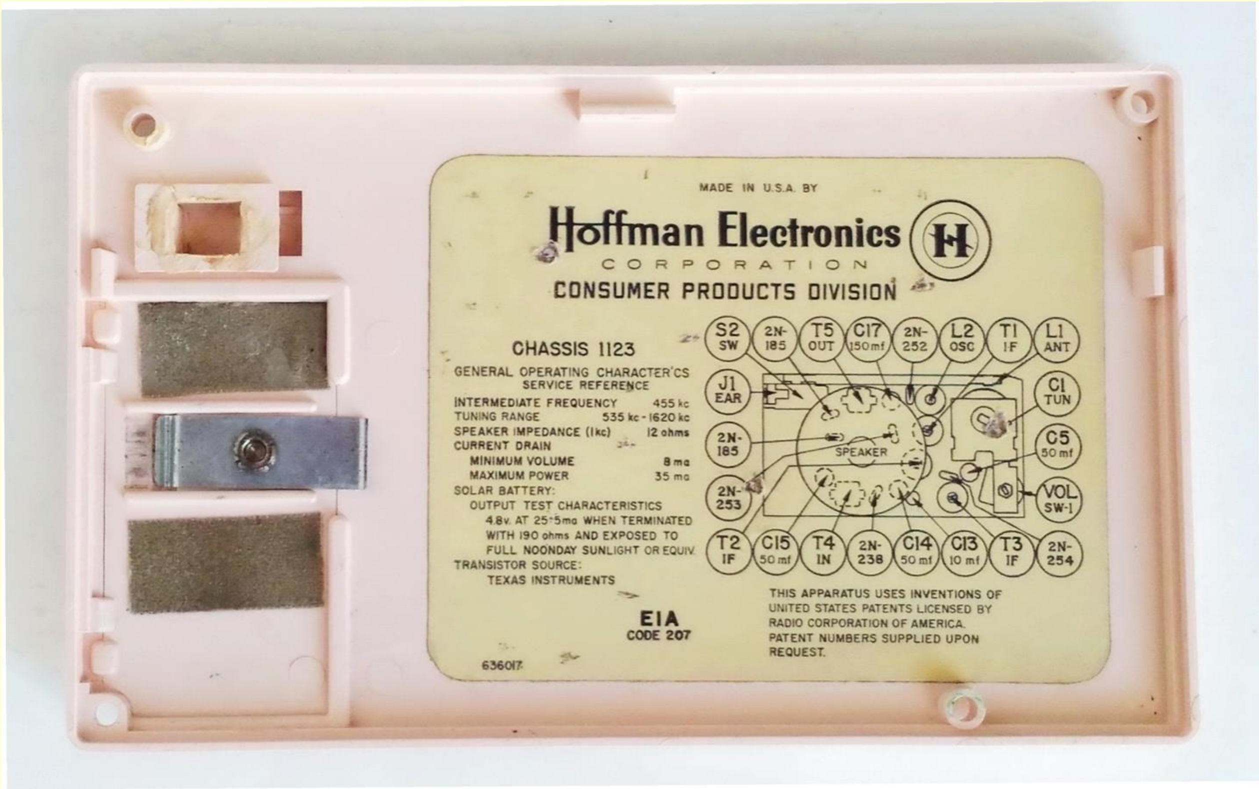

Fig.13 (mod. P P706 label)

therefore without the sockets as in the P411 model, and bear the letter "H" despite having been built, as the large label points out, by Texas Instruments. The transistors are germanium (and not silicon like the solar panel!) and while the two intermediate frequency transistors are of the npn type, all the others are pnp as in most of the radios built in those years. Externally, the large gold-colored micro-perforated metal grille on the left of the front side and the large tuning knob on the right, together with the beautiful metal dial, complete with the two CD marks[16]and alsodecorated with adrawing of the Sun surrounded by other stars together with the words, "Hoffman" and "TRANS-SOLAR", all in gold, make this radio a very attractive and desirable object.

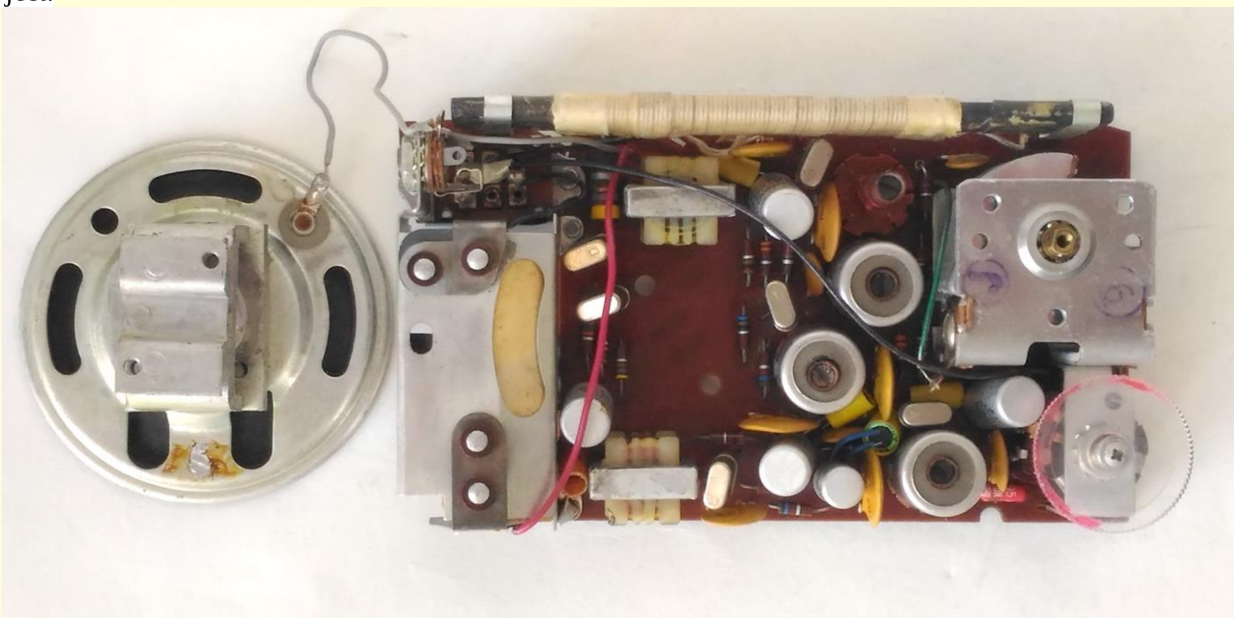

Fig.14 (mod. PP 706, chassis, parts side)

From the Los Angeles Times of June 08, 1958, welearnthatthis model wasintroduced the previous day by the Consumer Products Division of Hoffman Electronics Corp and asshown in the poster in Fig.11, its selling price was 75 USD, exactlyhalf of the expensivest P411.

The radio was available in six colors and in late 1958 a seventh was added, Oystar white. The complete series of colors of the P706 was alsodistinguished, as for the previous model, by a letter which, placed before the initials P706, specified the color of the cabinet. The available models were therefore indicated with the following abbreviations: BP 706 (moka), CP 706 (espresso), KP 706 (black), OP 706 (white Oystar), PP 706 (pink), RP 706 (red) and TP 706 (turquoise).
The first two Hoffman solar radios, as far as we know, were never marketed in Italy and my pink one, the PP 706 model, belonged for many years to a young Scottish lady from the Isle of Skye, Margaret Mac Innes, who moved in London, in Mayfair where she worked as a nurse and physiotherapist. After Margaret's early death, the radio remained in a drawer for a long time until one of her great-granddaughters, Donna, decided to put it up for sale on eBay, and from June 2021, Margaret's radio went on display, alongside her other sisters, in mycollection of transistor radios.

Hoffmam P709 and P719 models

After the success in the production and marketing of the "Trans-Solar", Hoffman introduced the 9-transistor Model P 709 (Fig.15),still in the BC (Medium Wave) band but a little narrower (from 535 to 1,605 kc), also with the lettering "solar" in relief at the top left on the front side and at an initial list price of 49.95$[17].

Fig.15 (mod. OP-709)

This third model, about 13 cm wide, approx. 8.1 and about 4.1 cm thick, smaller and more compact than the previous P706 (as was the style of Japanese radios) used Japanese components but mounted a Hoffman solar panel having dimensions of 12.3 x 3 cm and was available in four cabinet colors for which the series was distinguished by the following acronyms: BP 709 (brown), KP-709 (black), OP-709 (white) and TP-709 (turquoise) with the addition in some models of suffixes "X" or "XS". In the absence of light, this model operated with 3 non-rechargeable AA (penlite, the old US denomination) batteries. The P 709 model was followed, in early 1964, by the P 719 model (at the web address: https://solarmuseum.org/cells/hoffman-719/) the only solar powered with 7 transistors and also the last radio receiver of the Hoffman solar line. Both the 709 and 719 were manufactured in Japan rather than Los Angeles. And in fact already in 1959 several American companies (Bulova, Olympic, Magnavox, Columbia and even Motorola) were entrusting the production of their radios to the cheaper Japanese companies and Hoffman did the same, later divesting consumer electronics, as they found contracts with the military to be much more profitable.

Fig.16 (Tokay mod. P711 "solar")

Thereisalso a slightlydifferentversionof the P 719, the P 711 model (Fig.16), which has no CD-marks and instead of the Hoffman logo bears the writing TOKYO or TOKAY, the Japanese company Tokai Wireless Co., Inc. whereall the latter models weremanufactured. Both the 719 and the 711 werepowered by four AA-typebatteries, had the writing "SOLAR" on the front, the 719 at the top right and the 711 at the bottom left ("solar") and wereobviouslyequipped with the appropriate switch for changing power supply in case of insufficientsunlight. Their cabinet measured 14.3cm (W) x 10.2cm (H) x 4.3cm (D) and contained a battery holder for four AA batteries. The initial list price for the Hoffman 719 was $49.95, but as earlyas April 1964, some outlets were advertising this radio for just under $40.

In those years and until the first half of the 60s Hoffman dominated the market of these brand new products, miracles of science, which besides being beautiful to look at were well built and perform well. Hoffman even produced small photovoltaic panels that could be connected to transistor radios of all brands powered by 4.5, 6 and 9 volt voltages. Also in the mid-1960s, similar solar panels were also being supplied by International Rectifier Corp. and Radio Shack.

Other Solar Radios

Even before the arrival on the market of the Admiral 7L series (1956) and the Hoffman P411 (1957) and P706 (1958) models, other companies and other technicians had experimented and built sets running on solar cells, but these had never entered into production. It is necessary to mention the engineer of General Electric of Syracuse, (NY), Edward Keonjian, born on 08.14.1909 in Tibilisi (Republic of Georgia) and of an Armenian family, professor of microelectronics as well as author of many publications and numerous patents, who in early 1955 created a small transistor radio transmitter, about the size of a cigarette pack, which transmitted within a range of over 30 meters (100 feet) and was powered by a selenium solar cell. Keonjian had stated that the range of his midget transmitter could be extended by adding more selenium cells or by trying to use the newly invented silicon cells instead (from Popular Electronics 02/1955, p. 47). Keonjianhimself, together with another GE engineer, James O' Hearn created an experimental transistor pocket radio receiver powered by a solar battery, and the news and the photo of this radio held in Keonjian's own hand werepublished in the newspapers of that era, respectively in the Ithaca (NY) Journal of January 16, 1956 and the Richmond (VA) Times-Dispatch of February 5, 1956. Again, in the years 1956 and '57, in addition to GE, two otherwell-known American companies also ventured into the intent to power their transistor radios with solar energy: Magnavox, whoexperimented with their AM-2 model, and Texas Instruments, who made a pair of 22.5-volt solar panels roughly the same size as their early radio models, the TR-1 and TR-1G (7.62 cm wide and 12.7 cm high) that they wanted to feed. All three of these companies remained in the experimental field, never bringing finished products to market (source: Bill Burkett, note 12). It should also be remembered that between 1956 and up to the early 1960s there were various radio magazines and companies, including those constructing educational games (such as, for example, E.E. Fairchild), which offered experimenters and hobbyists the creation of radio receivers with germanium crysta ldiode (type 1N34, 1N69, etc.) with earphone listening, as well as kits to be assembled powered by very small solar panels. The circuit diagram of one of these experimental radio receivers (probably the first) together with the list of components used, including a crystal diode, a transistor, an additional antenna and a B-15 type selenium cell, appeared in the March 1956 issue, page 34, of Radio-Electronics

Fig.17 (Acopian mod.257 P-E solar radio) \ (magazine of the famous publisher, Hugo Gernsback) signed by Edwin Bohr and was also advertised in a 32-page catalog, the Lafayette T4-56. This scheme was recurrent and similar to that of the 257 P-E model, made and sold for $12.95 (plus F.E.tax) by Acopian Technical Co. of Philippsburg, Parkside (New Jersey) (Fig.17). Thomas A. Workman and SarkisAcopian, two young thirty-year-old university friends as well as partners of Acopian evidently taken by the enthusiasm and incompleteness of the means of communication of that era in a country as large as the United States, believed that their solar-powered radio was the first of its kind, and the news was given in an article that appeared in the Easton Express on Saturday, May 11, 1957. Although it was a simple radio, little more than a toy as someone said, a radio, among other things, without a speaker and in need of an antenna, the price of the mod. 257 P-E was convenient and served to introduce the most curious to photovoltaic energy and to the experimentation of electronic circuits since soon after the kit version called "Workchest" also appeared, visible on the Acopian website, a company that currently (2023) builds electronic power supplies (https://www.acopian.com/radiohome.html). Among the other manufacturing companies in the indicated period of such radio sets powered by solar panels, we should mention, in addition to Acopian and E.E. Fairchild**:** Lafayette with its KT-132 "Sunflex" model with two transistors and reflex circuit and still with earphone listening; Philmore/Midland, Science Electronics of Cambridge (Massachussets), the Alfred Carlton Gilbert Company and the aforementioned International Rectifier, which distinguished itself from all because it produced small solar panels by itself and in 1962 launched the EP model at a price of $19.95 -6, the only radio receiver among those of the aforementioned companies equipped with a loudspeaker inside. A YouTube

visit to the following web address is well worth it to see this unit showcased by one of the world'smost experienced collectors of pocket transistor radios, Eric Wrobbel: https://www.youtube.com/watch?v=phGISvGUWRk.
Leaving the world of the experimenter and hobbyist and returning to standard radio sets, the superheterodyne ones for normal daily use by anyone, in addition to the various models produced by Hoffman and by the Japanese Tokai on behalf of Hoffman, other companies brought out radios equipped with photovoltaic panels. In 1960 Stromberg-Carlson of Australia, founded in 1927 by Leslie P.R. Bean, with the participation of the US parent company, produced the 7-transistor medium wave portable model, the 70T11, also known as the "WayfarerSolarsound", available in both the solar powered and standard versions only. In the solar version, the panel wasmounted at the top and was supplied by Hoffman, identical to the one mounted on the 709 model. In the standard version, this radio, using a special base applicable under the dashboard, also became a car radio by connecting the antenna mounted on the bodywork of the car and drawing current not from the car battery but from its internal battery made up of 4 C-type batteries (half a torch in Italian language). This Australian radio and the Hoffman Models 709 and 719 were the only solar radios of this period manufactured outside the United States.

Fig.18 (Zenith Royal 555, the "Suncharger")

On the other hand, the portable 8-transistor model, in Medium Waves only, produced in 1965 by the prestigious Zenith Radio Corp. of Chicago, the Royal 555(Fig.18), was of American construction.[18]named, "SunCharger", externally identical to the Royal 500 N model and different from this due to some internal modification of the circuit. The 500 N wasequipped with the 8NT40Z8 or 8NT40Z9 chassis and could be powered either with 4 standard AA batteries or with a special external AC power supply supplied by Zenith and having a 6 volt DC (directcurrent) output to be connected to a jack plug on the back of the radio. The 555 model instead had the solar cells in its large handle which, due to the presence of this solar battery, was euphemistically called the "MiracleSunray Handle". This radio mounted either the 8NT42Z8 or the 8NT42Z9 chassis (the schematic lies in radiomuseum.org!) and could be powered in three ways: with the solar panel, with 4 rechargeable nickel-cadmium AA 1.25 volt batteries or with the voltage of the electrical outlet at 125 volts, (50/60 cycles). The batteries were recharged both with the photovoltaic panel and with the 125 volts. The Royal 555 Suncharger was available in charcoal and white, identified as 555C-N and 555W-N respectively, and retailed for $59.95. For the collector, it is certainly interesting to know that for its creation, Zenith commissioned, as for its other products, the design studio Mel Bolt & Associates, also obtaining the patent n. 206492 on 12.20.1966. The Royal 555 model and the Royal 500 N itself werere named Royal 56 and Royal 41 respectively and the same happened with some of their other models between the mid and late 60s without any particularly significant changes being made to them. After the Zenith "Sun Charger" of the mid-60s, with the exception of the veryfew kits sold in the early 70s by Graymark and Radio Shack, interest in solar-powered radios and the long production stasis of this type of sets lasted until the mid-1980s when the first radio receivers powered by small solar panels and listenable only with earphones or headphones began to arrive from the Far East, certainly on the American market (see Note 13). But this is another story, a more recent one that someone will be able to tell in the future much better than me.

Epilogue

Fig.19 (Solar roof in Salorno, Alto Adige/South Tyrol, Italy)

The invention of the Bell solar battery certainly marked the beginning of a new era, and the author of the article that appeared in the New York Times on April 26, 1954 was right on point. Sixty-nine years have passed since then, and today (A.D. 2023), with the reduction of fossil energy reserves (coal, oil, natural gas) but above all with the harmful consequences on the whole planet Earth of climate change triggered by human activities and due to he pollution produced by the combustion of these traditional energy sources, humanity has found in photovoltaic cells (and, in terms of ecological transition, not only in them!) a valid alternative for producing energy in a clean, renewable way. The photovoltaic cells used today are mainly silicon and derive from the one invented by Chapin, Pearson and Fuller. Their efficiency has reached and exceeded that limit of 23% that Chapin had theorized. From conventional silicon or first generation cells we have moved on to second and third generation ones, i.e. solar cells that exceed the Shockley-Quisser limit of 31-41% energy efficiency. Scientific research continues and at the moment, the most promising of the latest generation solar cells are those that use, together with silicon, new materials such as perovskite[19]

From the approximately 50 watts per square meter (sorry, square yard!) of Bell Laboratories' first silicon solar cell has now come to produce billions of watts of electricity, renewable electricity from solar PV power plants, solar PV rooftops (Fig.19) and by photovoltaic modules and panels for the most diverse uses. In the last twenty years, between ups and downs, the production of electricity from photovoltaics has continued to grow with a notable acceleration in the last five. Among the 27 states of the European Union, the total installed power as

at 31.12.2022 was approximately 209 GW (billions of Watts) with Germany leading the way in photovoltaic installations followed by Spain and Poland[20]
We can then firmly state that one of humanity's most cherished dreams, that is, the exploitation of the sun's unlimited energy for the uses of civilization, has come true. LONG LIVE SCIENCE!

(The End)

Notes, bibliography and web references (in order of consultation)

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Notes and thankswords

- The photo of the three scientists is from the AT&T archives and comes froman articlewritten in 2004 by John Perlin (https://www.nrel.gov/docs/fy04osti/33947.pdf)
- Transistor radio collector Russ Abrams providedphotos of the Hoffman P-411 model
- Alan Kastnerhasbeen keeping a site full of information and photos of splendidtransistor radio sets on the web for over twentyyears. It is a must to visititat: http://www.tabiwallah.com/radiowallah/index.html.
- JoeHaupt, transistor radio collector, provided the photo of Fig.11 and otherusefulinfoson this model.
- Manfred Ehlert, German colleague and radio friend for the photo of Fig. 16.

A big thank you to all these people.

A special Thanks to my radio friend Bob Davidson for his editing work on this article

This article, as synthesis of my knowledge and research on the subject carried out above all in the boundless world of the web, is intended as my small contribution of information to be shared with collectors and with those interested in the history of technology. Anyone can draw from this article and the only thing I ask is to cite the source (Lello Salvatore) for the commitment and work done. Thank you verymuch!

(* lello.salvatore@libero.it or raf.salvatore@libero.it)

Termoli (CB), May 12, 2023

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[1] *Available and downloadable for free, together with manyother American vintage electronics magazines, directly on the site: https://worldradiohistory.com/Archive-Radio-News/50s/Radio-News-1954-07-R.pdf. A big thank you to these people!*

[2] *At https://www.youtube.com/watch?v=-_4fGMF25Cs a short and valuable archive film from Bell Labs shows these experiments. Another video, very explanatory of the topic, is available, again on YouTube at the address https://www.youtube.com/watch?v=3I1JhyOahIw*

[3] *The entire article can be read at the following web page: https://www.nytimes.com/packages/pdf/science/TOPICS_SOLAR_TIMELINE/solar1954.pdf?scp=1&sq=Vast%20Power%20is%20Tapped%20by%20Battery%20Using %20Sand%20Ingredient&st=cse*

[4] *This value is reported both in the aforementioned New York Times article and in the ad published on page 24 of No. 7/1954 of "RADIO & TELEVISION NEWS". A square yard is the area of a square with a side of 91.44 cm, i.e. equivalent to 0.8361 square meters (about 1 square metre).*

[5] *In Greek mythology, Apollo (in ancient Greek Apollon), often identified with Helios, was the shining god of light, the Sun. He is depictedas a young man of extraordinary beauty who drives a chariot drawn by four winged horses to carry the burning star, the Sun, across the celestial vault.*

[6] *The p-n junction is the fundamental building block for the design of all semiconductor devices. It was discovered by serendipity (unexpectedly and fortunately) during an experiment conducted on February 23, 1940 by the electrochemical scientist of Bell Laboratories, Russell Shoemaker Ohls. It is also due to this scientist, often forgotten, the discovery of the photovoltaic effect in semiconductors which led to the invention of the "Solar Battery" also based on the p-n junction. At the bottom of the Solar Battery patent paper, Ohl's patents are mentioned, among others.*

[7] *The National Inventors Hall of Fame (NIHF) is celebrating its 50th anniversary this year. The NIHF website can be reachedat: https://www.invent.org/inductees*

[8] *The silicon solar cel lpatent is available at the following web address: https://patentimages.storage.googleapis.com/36/ee/af/d21dacd3884160/US2780765.pdf*

[9] *From Radio-Electronics magazine No.1/1956, page 32.*

[10] *These were the very early junction transistors to have practical application. It was 1858 and 1859 that were "baked out" in 1952/53 by the Allentown plant of Western Electric. They were enclosed in an oval-shaped metal case (seen from above) in black for the first version and silver for the second, which appeared in 1953 (respectively the second and third from the left in the photo in Fig.5) and derived from the experimental transistor signed 1752 (the first on the left of Fig.5) built in 1952 and enclosed in a plastic case. A beautiful and detailed history of these transistors (from which Fig.5 is taken) and many others can be found in Jack Ward's "The Transistor Museum" at the web address: http:/ /semiconductormuseum.com/Museum_Index.htm*
A veryheartfelt thanks (!) to Jack for the great work he has done and for keeping this precious site up to date.

[11] *Taken from "Power from the sun", page 33, number 1, January 1959 of Popular Electronics, a well-known American electronics magazine of those years. Through these unforgettable magazines, the lucky US electronic experimenter could simply see or buy cheap selenium solar cells for his experiments (the B2M, the most popular one), not the new silicon ones which were much, much more expensive. "The International Rectifier Corporation (1521 East Grand Ave., El Segundo, California) was the leading manufacturer of these selenium cells as well as rectifier diodes. A curiosity is that the cover of this issue of Pop.El. was partially reproduced from the Italian same period magazine "La Tecnica Illustrata" N.9 September 1959 which put on display a man grappling with a Hoffman transistor radio with solar panel without mentioning the set at all.*

[12] *From The New York Times dated 07/05/1955: https://www.nytimes.com/1955/07/05/archives/chicago-concern-sold-national-fabricated-products-goes-to-hoffman.html See also: https://solarmuseum.org/history-of-early-solar-powered-radios/*

[13] *From "Museum of Solar Energy" (MOSE) at web address: https://solarmuseum.org/cells/admiral-sun-power-pak/. On this site, Bill Burkett, an old American collector of transistor radios, documents, in a timeline that crosses the press reports that gradually appeared in the various US newspapers of the time, the origin of the first solar powered radios until the appearance of the most recent models, not yet vintage, from the Far East. His very interesting article, published while I'm writing mine, is available in pdf format at the web address https://solarmuseum.org/wp-content/uploads/2023/03/Timeline_3-28-23.pdf: A heartfelt thanks to Bill Burkett, a collector like so many of us, for the good work done.*

[14] The term photovoltaic takes its name from the Italian physicist, chemist and pioneer of electricity, Alessandro Volta, inventor of the electric battery (1799/1800). The term is used interchangeably with the photoelectric term but it is the more technical one to indicate the transformation of light energy into electrical energy through the photoelectric effect that occurs inside semiconductors. The theory of the photoelectric effect was formulated in 1905 by the Swiss scientist Albert Einstein who by applying the quantum theory of the German Max Plank introduced the concept of quanta of light, commonly known as photons. For explaining the theory of the photoelectric effect, Einstein was awarded the Nobel Prize in Physics in 1921.

[15] Photo visibleat the web address https://americanhistory.si.edu/collections/search/object/nmah_1805542 and publishedby courtesy of Mrs. Peterson of the Division of Work and Industry, National Museum of American History, Smithsonian Institutionwho I thank

e pubblicata per cortesia della Sig.ra Peterson del "National Museum of American History" che si ringrazia.Division of Work and Industry, National Museum of American History, Smithsonian Institution

[16] They are thoset wotriangles of the Conelrad Civil Defense that can be seen on the tuning dial (dial scale) of radios built and sold up to 1963 in the USA, placed at the frequencies of 640 and 1,240 kc.

[17] An advertising poster of this model appeared in the Boston Globe Newspaper of December 10, 1961, as reported by Joe Haupt in the picture of this advertisement which can be found at the web address: https://www.flickr.com/photos/51764518@N02/33829310978/in /album-72157633171174367/

[18] For further information on this model and on the 500N, as wel las on many radio receivers for radio listening enthusiasts, see Jay Allen's interesting site at the following web address: https://radiojayallen.com/zenith-royal-500n-g-royal- 555g-suncharger-am-radios/

[19] See "Solar PV Technology: A Review of Different Solar Cell Types and Its Future Trends" at: https://iopscience.iop.org/article/10.1088/1742-6596/1913/1/012053/ pdf

[20] As reported by the "Solar Power Union" report downloadable in pdf at the web address: https://api.solarpowereurope.org/uploads/5222_SPE_EMO_2022_full_report_ver_03_1_319d70ca42.pdf?updated_at =2022-12-19T08:21:34.541Z