AWA Review

How Dunwoody's Chunk of 'Coal' Saved both de Forest and Marconi

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ABSTRACT

The success of wireless telegraphy pioneers Marconi and de Forest owes much to the invention in 1906 of a simple, reliable detector of wireless signals by a then-retired Army General, Henry H.C. Dunwoody. He showed that carborundum could act as a stable and sensitive detector, permitting the wireless operators of the day to hear even transatlantic signals. The carborundum detector got de Forest out from under what would otherwise have been a company-killing injunction obtained by Fessenden, whose electrolytic detector patent de Forest infringed. It also facilitated the development of a noise cancelling circuit essential to Marconi's long wave transatlantic success as early as 1907 and up to the vacuum tube era. For a decade it was state -of -the -art, stabilizing the circuits and operations of wireless telegraphy and thus fostering new directions of innovation.

Fig. 1. This undated photograph of Brigadier General H. H. C. Dunwoody, circa 1904, shows him in the dress uniform of the era. [1] The yellow sash is a decoration for bravery in the Spanish American War in Cuba.

United States Army Brigadier General Henry H.C. Dunwoody is little known today. Yet he invented the crystal detector of wireless spark signals about March, 1906. In the early twentieth century his device came to be known as the "heart of radio." Dunwoody's crystal detector saved Lee de Forest from a federal injunction sued out by Reginald Fessenden, and then saved the Marconi Company from the long-wave static that challenged the first transatlantic circuit from Ireland to Nova Scotia in 1907 and subsequent years.

General Dunwoody had a distinguished military career, serving in Cuba during the

Spanish American War, and living to 90. He was widely honored for his leadership of the U.S. Weather Bureau in the 1880s. In 1883 he wrote a book Weather Proverbs (still available) compiling folk wisdom about weather in order to make better predictions. The Arlington National Cemetery [2] summarizes his military career:

"Henry Harrison Chase Dunwoody of Ohio [:] Appointed from Iowa, Cadet, United States Military Academy, 1 September 1862[;] Second Lieutenant, 4th U. S. Artillery, 18 June 1866... Major, Signal Corps, 18 December 1890[;] Lieutenant Colonel, 15 March 1897[;] Colonel, Chief Signal Officer of U. S. Volunteers, 20 May 1898 [Cuba][;] Colonel, Signal Officer, U. S. Army, 8 July 1898 [retired as a Brigadier General, 1904][;] Died 1 January 1933."

West Point was a leading engineering school of the day; Dunwoody graduated 19th in his class according to its records. After he retired from the Army and after a brief interlude with the de Forest enterprise, he manufactured armaments in several companies, part of the original military-industrial complex. Arlington Cemetery posts [2] a newspaper feature article (and obituary) telling of his life and success as a meteorologist as well as the inventor of what it called the Heart of Radio:

"*Fairfield Weekly Ledger-Journal* August 30, 1928. Inventor of 'Heart of Radio' Is a Former Fairfield Citizen. General H. H. C. Dunwoody went from here to West Point; was in Charge of Weather Forecasting for the Weather Bureau for Years, and headed the Signal Corps of the American Army in the Cuban Campaign. Old timers remember Gen. Henry H. C. Dunwoody when he was a boy in school here

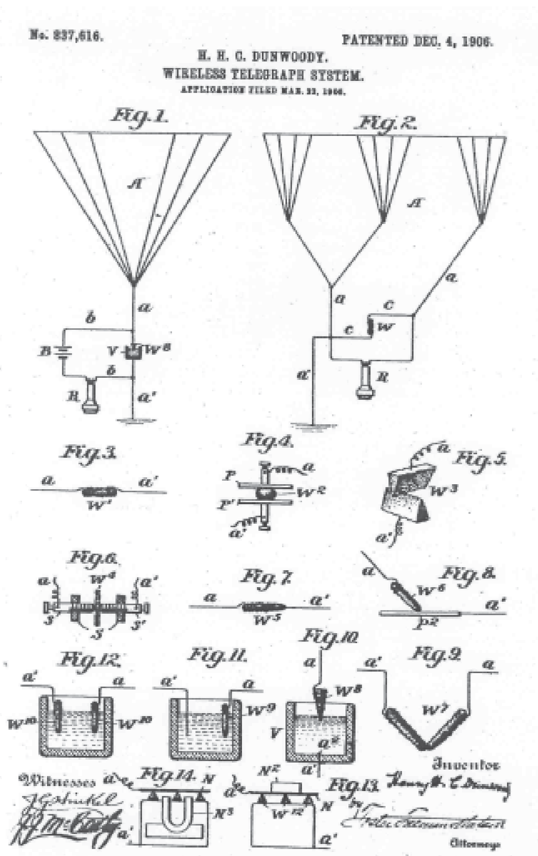


Fig. 2. Dunwoody 1906 carborundum detector patent, number 857616. Note that circuit figure one uses DC bias. Marconi used this as a basis for his detector circuit. Note figure four displays the carborundum between two steel plates, which came to be the usual configuration because of its mechanical stability. One of the patent claims is that the detector will not burn out when in proximity to a transmitter, an important advantage shipboard as well as in shoreside installations with co-located receiver and transmitter equipment. The patent omits tuning circuits.

and up to all the pranks of a lively lad. He was born in Highland County, Ohio, Oct. 23, 1842, and so is in his 86th year. He now lives at Ovid, New York."

Gen. Dunwoody employed carborundum (which he called crystalline silicid of carbon), under mechanical pressure and electromotive pressure (i.e., with a bias voltage) to detect wireless telegraphy signals. [3] His patent appears in Fig. 2.

The substance Dunwoody worked with is now known as silicon carbide. Nineteenth century chemist Edward Acheson accidentally created this artificial compound in his search for a way to make diamonds. [4] Dunwoody discovered its semiconductor properties. It was for this discovery that he was later said to have invented "the heart of radio." As this note will show, his invention sustained the success of the two most important early wireless telegraphy companies.

Prior to Dunwoody's invention, Chandra Bose, the Indian physicist, discovered the rectifying properties of galena (lead sulfide) and patented a detector of Hertzian waves (microwaves) that employed these and related properties. (The priorities of Bose are widely discussed in recent literature [5]). Karl Ferdinand Braun also developed a rectifying crystal diode at least as early as 1898.

A little after Dunwoody, another wireless experimenter, Greenleaf Whittier Pickard, invented a complete wireless receiving system (a "crystal set" that was tunable) in August, 1906, using silicon alone and what came to be known as the "cat's whisker" interface. His patent [6] appears in Fig. 3.

Before the crystal detectors, commercial, naval and amateur wireless signals were detected, i.e., made hearable or readable, by use of the Edouard Branley filings coherer, the John Ambrose Fleming valve vacuum tube diode, the Marconi magnetic detector (colloquially known as the "maggie"), and by electrolytic processes (primarily discovered by Canadian Reginald Aubrey Fessenden).

Lee de Forest employed General Dunwoody in 1906 in New York, after he retired as the Army's Signal Officer. In his autobiography *Father of Radio,* [7] de Forest says of the carborundum device that it was: "... a simple rectifier which had been discovered by General Dunwoody, former chief Signal Officer, and now vice-president of the company", i.e., the de Forest Wireless Telegraph Company, Inc. De Forest brags about how much better the carborundum detector is than the Marconi magnetic detector for "reading through interference or static." He delights in calling Marconi Company wireless operators "limey Sparks." He says that many a "limey Sparks," in order to effect better reception of Marconi stations' spark signals, took to "concealing about his person a small chunk of 'coal,' as the Dunwoodie [sic] carborundum was later called."[8]

The wireless companies of the day prohibited use of non-company devices, to avoid patent infringement claims. Hence the need for concealment. But a clever Sparks could substitute the better carborundum detector for a Marconi detector at sea, with no one the wiser.

At the time (and as always) de Forest was challenged by litigation. The Canadian wireless pioneer Fessenden in particular had sued de Forest about commercial use of an electrolytic detector that Fessenden had invented about

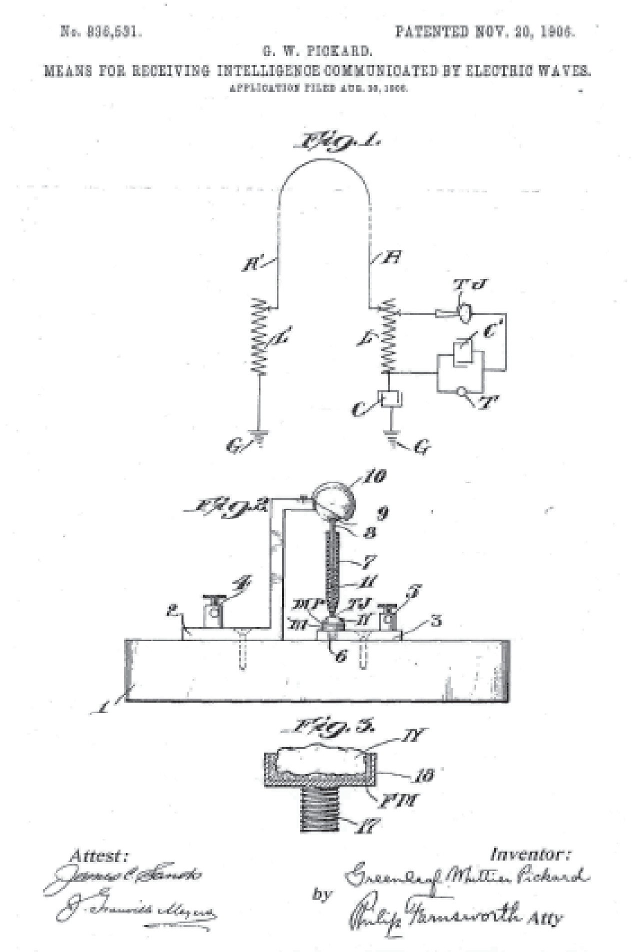


Fig. 3. Pickard "crystal set" patent of 1906, number 836581, employing silicon and what came to be called a "cat's whisker" contact with the silicon. Pickard claimed silicon as a wireless detector that did not require a bias voltage with the inconveniences of batteries and the like. His circuit isolates the detector and its tuning from stray capacitance and body proximity effects.

1903. De Forest in his autobiography goes on to say that the American De Forest Wireless Telegraph Company's directors had decided to use, at the company's stations, the Dunwoody carborundum detector. They in effect decided to forego de Forest's legally problematic "spade" electrolytic detector at issue with Fessenden. De Forest almost by accident no longer infringed Fessenden's patent. De Forest gloated about the unhappy consequences for Fessenden's litigation of his directors' decision: "... happily for me as it later turned out." [9]

Dunwoody's invention of the carborundum detector thus saved de Forest's wireless enterprise. Fessenden had persuaded a court to issue an injunction against de Forest's use of any electrolytic detector. Dunwoody's detector worked as well and likely better, thus avoiding the sanctions of the injunction and permitting the company to remain in business. [10]

The judge's findings of fact and legal opinions in the detector injunction United States Circuit Court lawsuits were officially reported for their precedential and technical value, and may be found in the *Federal Reporter* series of law reports.[11] De Forest's detector litigation reached an acme in the Audion and Fleming Valve dispute in 1916 [12]. This U.S. District Court judicial opinion discusses detectors, including Dunwoody's, at length.

One of the further advantages of the Dunwoody carborundum detector in marine service, beyond its sensitivity, was that it was mechanically very stable. This was so because in its initial implementation two metal plates held the "coal" firmly. De Forest also concluded that its sensitivity was independent of the pressure of the contacts. [13] There is some data on relative sensitivities of early detectors. Carborundum appears to be about as good as the "maggie," and not as good as silicon, see Fig. 4. [14]

The year 1906 was said at the time to have delivered the worst atmospheric static that the nascent wireless art had yet faced. Sunspots also peaked in 1906 - 07 [15] although no one at the time understood any connection with radio propagation or the auroral effects on it. Atmospheric static, especially on what we now call the long waves, was the bane of operators world-wide. In mastering this challenge, the carborundum detector played an important role in the development and success of Marconi's international wireless circuits as early as 1907.

Marconi's first working transatlantic circuit connected Clifden, Ireland with Glace Bay, Nova Scotia. A Nova Scotia archive [16] describes the role of Dunwoody's chunk of "coal" in this initial and successful first transatlantic circuit and some subsequent refinements:

"The construction of a receiving station in Louisbourg, Nova Scotia and a similar one in Letterfrack, Ireland in 1912-1913 represented the final phase of the establishment of the first transAtlantic radio communications service.

"The first Louisbourg detector was the carborundum detector, a rugged crystal detector invented by General H.C. Dunwoody of the U.S. Army. Marconi used a circuit called the "balanced detector,"in which two carborundum diodes were connected and electrically biassed [sic: biased] in such a way that strong impulses produced by lightning discharges would tend to cancel out, whereas the weaker signal that the operator was trying to copy would be detected."

The balanced carborundum crystal detector circuit appears to have been developed primarily by Marconi engineer H. J. Round. He later, on behalf of the Royal Signal Corps, worked with Major Edwin Howard Armstrong during

Table 10.1 *Edelman's comparison of detectors (1915/16)*
[EDELMAN, P.: *Experimental wireless stations* (published by Edelman at Minneapolis, 1915/16) p.160]

TABLE OF DETECTORS–SENSITIVENESS

Type of detector	Energy required to operate in ergs. per dot.
Electrolytic	0.003640–0.000400*
	0.007 §
Silicon	0.000430–0.000450*
Magnetic hysteresis detector	0.01 §
Hot-wire barretter	0.08 §
Carborundum	0.009000–0.014000*

* According to Pickard.
§ According to Fessenden.

Fig. 4. Table of relative sensitivities of wireless detectors from V.J. Phillips. [14]

the First World War. His work on the balanced detector circuit resulted in the Marconi Model 16 balanced Crystal Detector circa 1916.

Marconi engineer Elmer T. Bucher, in *Practical Wireless Telegraphy*, (1918) provides circuit details and a wealth of technical information on the carborundum detector. [17] See the graphical appendix to this note for Bucher's illustrations of the characteristic curve of carborundum, his analysis of its workings as a biased detector and two Marconi implementations of the steel and carborundum detector.

The Bucher schematic in Fig. 6. correlates with the Model 16. It worked by listening only on one crystal by holding the bias voltage on the other too low. The sharp input voltage of a static crash, however, moved both crystals high on their characteristic curves, and the resulting nearly equal detected voltages canceled each other out.

Note the top right buzzer circuit to enhance audibility of the detected almost-continuous-wave signals, known as undamped spark signals, which Marconi rotary spark transmitters

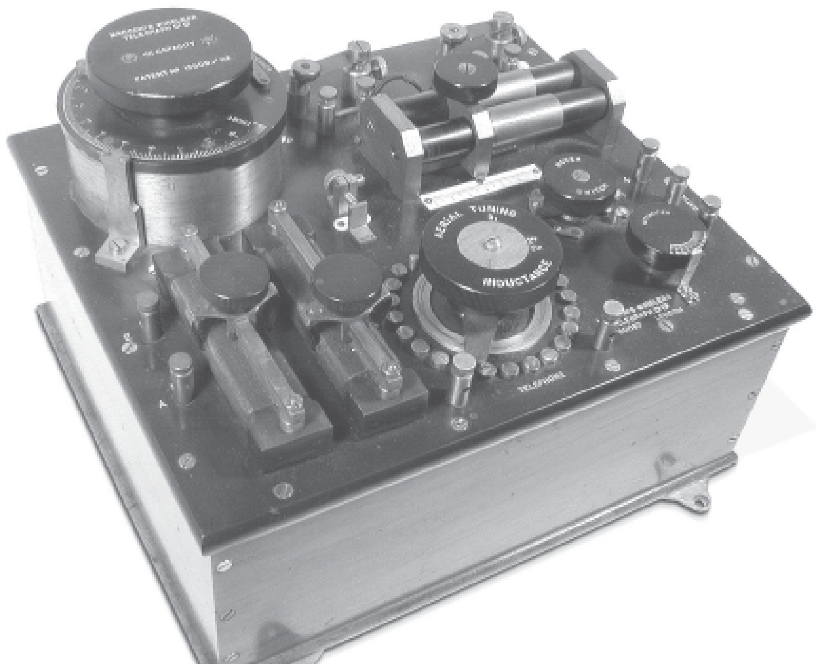


Fig. 5. The Marconi Model 16 balanced Crystal Detector circa 1916 at the Bellingham, Washington, American Museum of Radio and Electricity of John D. Jenkins. See: http://www.sparkmuseum.com/MARCONI.htm; copyrighted image used by permission. Note the two sliding linear rheostats at the bottom left, used to unbalance the bias voltages so that only one carborundum detector worked at a time (until a static crash activated both, cancelling the crash). Note also the adjustable tubular capacitor at the top right, which looks like the "Billi condenser," the last variable capacitance in the tuning circuit, the "secondary circuit," of the American Marconi Type 107A tuner, which also used carborundum as its primary detector.

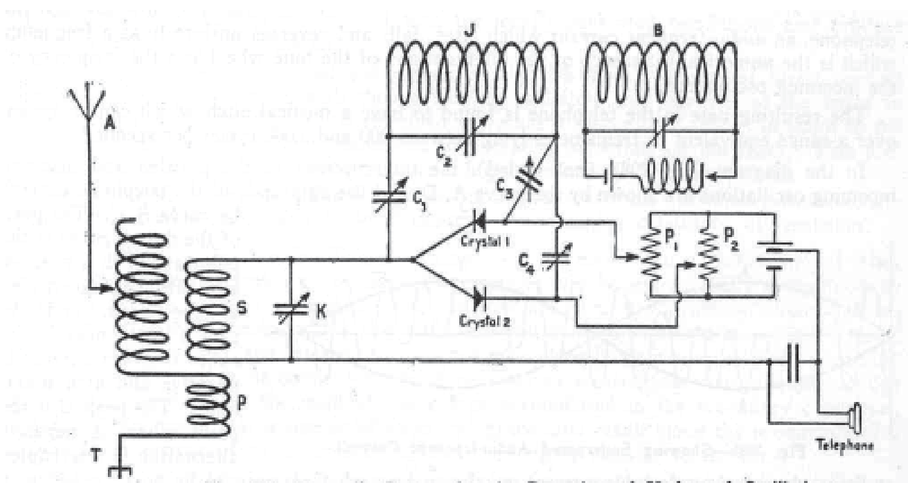


Fig. 300—Marconi's System for the Reception of Undamped Oscillations.

Fig. 6. Round's circuit for using two balanced carborundum detectors to minimize static in CW reception (Bucher's Fig. 300 B Marconi's System for the Reception of Undamped Oscillations) [17].

generated. Thus, by taking advantage of the characteristic curve of the biased carborundum rectifiers to cancel out strong signals (lightning crashes) but pass weaker signals of intelligence by one or the other detector, Marconi mastered atmospheric static. In the later development of this device, a tuned buzzer provided a heterodyne to make undamped (continuous wave) signals audible.

It is thus fair to say that Dunwoody's "coal" may well have saved the two most important wireless communications companies in the nascent days of the radio art, before the use of the vacuum tube. Dunwoody's detector had the advantages of mechanical reliability, as compared to galena or silicon detectors using "cat's whisker" interfaces. Nor did wireless operators have to find or reset a "sweet spot" especially after each transmission. Carborundum's performance when biased permitted the development of the noise cancelling circuit, for which other detectors were unsuitable. The manufacture of carborundum presented no difficulty and it did not have to be mined and selected the way galena crystals, for example, did. Carborundum'sensitivity sufficed, especially in view of the tremendous power put out by the early commercial wireless transmitters, in the range of 300 kilowatts.

Dunwoody's carborundum detector bridged the receiving technology of the filings coherer of the early experimenters, including Marconi, and the later and soon dominant technology of the vacuum tube triode. Its availability, reliability and performance made it the detector of choice for nearly a decade, until the advent of Armstrong's regenerative circuit for de Forest's triode circa 1916.

In the absence of Dunwoody's discovery, both commercial and amateur wireless operations would no doubt have employed the several other minerals and detector technologies available, but at some cost especially in reliability. The great advantages of carborundum permitted the energies of innovation to focus on new circuits and techniques, and then on the quantum leap of vacuum tube technology for detection, amplification and oscillation, which provided the major electronic advances of the first half of the twentieth century.

NOTES

1. The source of the photograph of then Col. Dunwoody is a page in the Archive of the New York Public Library, No. 1227290, NYPL Digital Gallery.
2. Arlington Cemetary - http://www.arlingtoncemetery.net/hhdunwoody.htm . This goes on: "*Fairfield Ledger* Tuesday, January 3, 1933 Former Fairfield Resident Passed Away Jan. 1. Brig. Gen. Harry [sic; Henry] Harrison Chase Dunwoody, 90, former chief signal officer of the U. S. Army, died at Interlaken, New York, Sunday according to word received here by friends." It is interesting to note General Dunwoody's grandson Harold Dunwoody served in combat in World War Two, Korea and Vietnam, retiring as a much decorated Brigadier General. His great- granddaughter, Ann Dunwoody, is now the U.S. Army's first woman four star general officer.
3. Dunwoody's patent is number 837616 dated December 4, 1906, filed March 23, 1906.
4. http://www.reference.com/browse/all/crystal%20detector.
5. See, e.g., Tapan K. Sarkar, et al., An Appreciation of J. C. Bose's Pioneering Work in Millimeter and Microwaves, in *History of Wireless* (2006), John Wiley & Sons, at pps. 291-310.
6. Pickard's patent is number 836581 dated November 20, 1906, filed August 30, 1906.

7, 8, 9. Lee de Forest, *Father of Radio*, self-published, 1949, at pps, 127, 195.

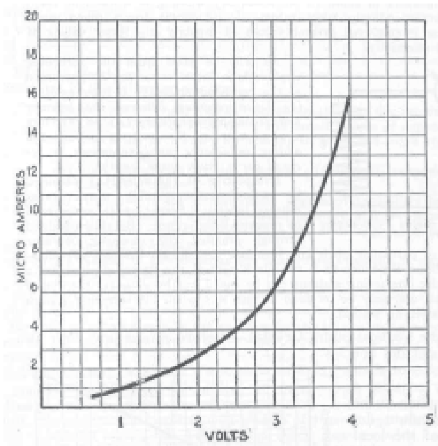
10. A. Douglas, "The Crystal Detector" *IEEE Spectrum* April 1981 p. 66.
11. National Electric S. Co. v. De Forest Wireless Tel. Co., 140 *F[ederal Reporter]* 449 (U.S. C.C.N.Y. 1905); National Electric Signaling Co. v. De Forest W. T. Co., 145 *F.* 354 (U.S. C.C.N.Y. 1906).
12. Marconi Wireless T. Co. v. De Forest Radio T. & T. Co., 236 *F.* 942 (U.S. D.C.N.Y. 1916).
13. Lee de Forest, in *Electrical World*, September 8, 1906 reported in D. McNicol, *Radio's Conquest of Space*, p. 125, -27 (Arno Reprint, 1974)).
14. V.J. Phillips, *Early Radio Wave Detectors*, (Science Museum, I.E.E., and Peter Perigrinus; London 1980) p. 213, Table 10.1.
15. E. W. Maunder [he of the Maunder Minimum episode of few sunspots], "The sun-spots of 1906 - II" in *The Observatory*, Vol. 29, p. 348-352 (1906) archived at: http://adsabs.harvard.edu/full/1906Obs....29..348M; see also for the intensity in 1907: http://adsabs.harvard.edu/full/1907Obs....30..126M .
16. The Official Research Site for the Fortress of Louisbourg (Nova Scotia, Canada) - http://fortress.uccb.ns.ca/Marconi/marconi2.htm.
17. Elmer T. Bucher, *Practical Wireless Telegraphy*, (1918) pp. 172, 286-87, 288ff and figs. 153 (a,b,c), 157, 157a, 158,163, 198, 199, 300.

This article was peer reviewed.

APPENDIX

The following illustrations from Bucher, *Practical Wireless Telegraphy* [17], provide graphical data on carborundum's performance as a detector and illustrate working Marconi Company detectors.

The so-called "characteristic curve" of carborundum (and other semi-conductors) is not linear, according to Bucher. (This is also true for other semi-conductors and vacuum tube diodes as well.) An



Bucher's characteristic curve for carborundum.

Assume a bias voltage of two volts. An alternating radio frequency (RF) voltage comes to the detector from the antenna and tuning circuit. Assume it is two volts peak to peak. The negative (subtractive) one volt peak will decrease the bias current flowing from three micro-amperes to one micro-ampere, down the curve as it were. The positive, additive one volt peak will, however, have a greater effect. It will move the flow of current from three micro-amperes to six micro-amperes. The effect is all the greater higher up on the curve, at three volts bias for example. Thus the detector permits more current to flow in one direction when under the influence of the alternating radio frequency voltage.

ordinary resistance curve is linear, i.e., the more voltage applied, the more current flows in an exactly proportional way: doubling the voltage doubles the current. A non-linear resistance on the other hand, permits a more than proportional current to flow as voltage increases. Bucher's curve for carborundum illustrates this characteristic.

Bucher then presents as his next stage of his explanation a diagram showing how the differential response to subtractive and additive parts of the RF input result in an average current flowing in only in one direction. He posits a bias voltage of three volts. The telephone receiver diaphragm integrates the

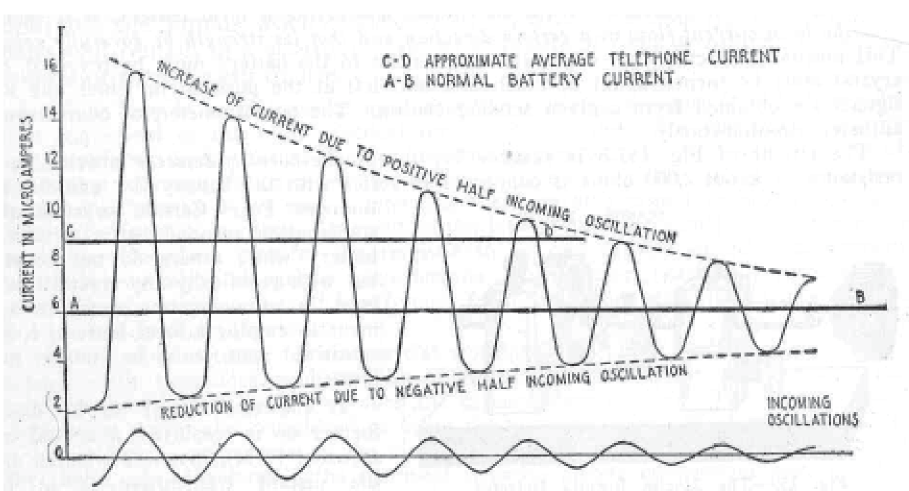


Fig. 157a.—Curves Showing the Fluctuations of the Local Battery Current flowing through the Carborundum Rectifier during the Reception of Signals.

Bucher's illustration of how the characteristics of biased carborundum make for asymmetrical if not one-way passage of RF and detection of it by way of differential current flows and mechanical integration by the telephone receiver diaphragm in response to them.

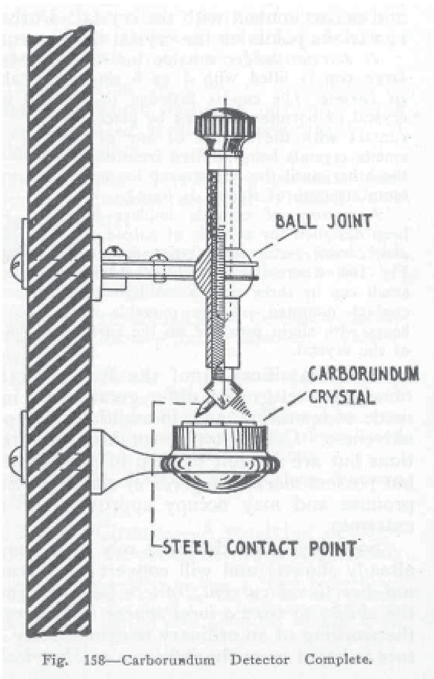


Fig. 158—Carborundum Detector Complete.

Marconi vertical carborundum detector.

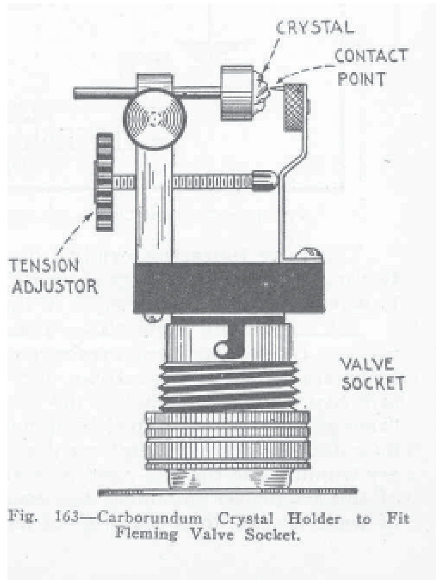


Fig. 163—Carborundum Crystal Holder to Fit Fleming Valve Socket.

American Marconi's substituted horizontal carborundum detector for a Fleming Valve.

additive larger pulses into a virtual larger steady current. Bucher summarizes the effect this way: " ... the added voltage due to the oscillating E.M.F. [electromotive force or voltage] being impressed on the crystal is greater than the subtracted voltage and that the final effect of this is an increase of current through the head telephone circuit over the duration of one wave train."

Marconi and de Forest had to reduce theory to practice. Bucher presents two illustrations of working carborundum detectors. The first is a vertical configuration, likely in use on a panel in shipboard installations. Bucher suggests use of a steel phonograph needle as the contact with carborundum in a holder, reminiscent of Pickard's holder for silicon as illustrated in his patent.

The second illustration also shows adaptive re-use. In 1904 Fleming had contributed the vacuum tube diode Fleming Valve to Marconi's operations. It was reliable but insensitive. According to Bucher, it was American Marconi Company engineers who cleverly affixed a horizontal carborundum detector to a screw base for the Fleming valve, permitting its substitution and use of the filament voltage as the bias. American Marconi had been De Forest Wireless, so perhaps that company's fondness for solid-state carborundum, even over the vacuum-state Fleming valve, carried over to this adaptation. It may also be the case that Fleming valves were hard to get and easy to break or burn out.

ACKNOWLEDGEMENT

I am grateful to the distinguished Spanish antique radio collector and historian Salvador Munoz Gomariz for stimulating my interest in General Dunwoody; I am happy to have supplied for his use the photograph of Gen. Dunwoody and an earlier draft of this article. See http://escibalofilms.blogspot.com/2009/01/henry-h-c-dunwoody.html.

ABOUT THE AUTHOR

Bartholomew (Bart) Lee, K6VK, xKV6LEE, holds an extra class amateur radio license. He has enjoyed radio and radio - related activities in many parts of the world, most recently in Singapore, Australasia, and the Papua New Guinea area. Radio history and technology have fascinated him since he made his first crystal-set with a razor blade and pencil lead detector more than 50 years ago. He is a widely published author on legal subjects, and most recently on the history of radio. He has written about radio in intelligence operations (from 1901 forward, including the CIA on Swan Island in the 1950s and 1960s), the history of wireless telegraphy, especially the work of Marconi and the independent developments on the U.S. West Coast, short wave radio and its history, radio ephemera including radio stamps, and radio in emergency and disaster response. Since 1989, he has made almost 20 annual presentations to the AWA Conference on his research interests, including the development of television in San Francisco in the 1920s. The AWA presented its Houck Award for Documentation to him in 2003 and the California Historical Radio Society made its 'Doc' Herrold Award to him in 1991 in connection with the Electronics Museum of the Perham Foundation. In 2001, during the New York City disaster recovery operations following the "9/11" terrorist enormity, he served as the Red Cross deputy communications lead from September 12 to September 21. Bart has also served as the San Francisco Auxiliary Communications Service Liaison Officer, and as an ARRL ARES Emergency Coordinator. He presently serves as an ARRL Government Liaison and Volunteer Counsel, and as counsel emeritus to the California Historical Radio Society. Bart is a trial lawyer by trade, and a former Adjunct Professor in Law & Economics at a San Francisco University. He is a graduate of the University of Chicago Law School, and St. John's College. He invites correspondence at KV6LEE@gmail.com.

Bart Lee photo by Paula Carmody, taken in Indonesia; copyright Bart Lee 2009.

Dunwoody