The coherer: with simple demonstrations of the generation, propagation and detection of radio waves

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Abstract
A coherer is a bistable device based on metal filings loosely confined between solid metal electrodes. This granular material normally exhibits a very high electrical resistance (tens of kilohms), but passage of the high-frequency current generated by reception of a radio signal causes it to ‘cohere’ into a comparatively low resistance condition (tens of ohms). This state persists until the device is mechanically disturbed, whereupon the high resistance state is restored. This characteristic was employed by scientists in the 1890s to detect radio waves, and applied commercially by Marconi in his ‘wireless’ telegraph.

It is easy to make a working coherer and directions are given for operating it from a distance with a spark transmitter based on a piezoelectric gas igniter.

Incorporation of an ‘aerial’ and ‘earth’ enable a range of 7 m to be achieved and simple signals may be transmitted.

In 1865 Clerk–Maxwell showed mathematically that light was explicable in terms of electricity and magnetism and that electromagnetic waves should be generated by the oscillation of charges flowing in a conductor. Hertz put this theory to the test in 1886 and found that long sparks from a circuit incorporating an induction coil would produce tiny sparks across a minute gap in an isolated loop of copper wire suspended some distance away. He and others soon realized that waves of longer wavelength than ordinary light were being emitted from the first circuit and then detected by their effect in the loop. These ‘radio’ waves excited great interest in the physicists of the time, but a major problem was to find more sensitive ways of detecting them.

The coherer

A solution—as in so many fields—came from the accumulated efforts of many investigators [1]. In particular the French scientist Branly, when in the 1890s investigating the electrical characteristics of finely divided conductors such as metal filings, found that the overall resistance dropped sharply when electric sparks were generated in the vicinity. The original high resistance was restored by any slight mechanical disturbance of the tube. Nowadays, it would be classified as a bistable device. This phenomenon was employed as a detector of radio waves by Popoff, Tesla, Bose and Lodge [2], the last-named bestowing the name ‘coherer’ from the way in which the particles appeared to make better electrical contact when

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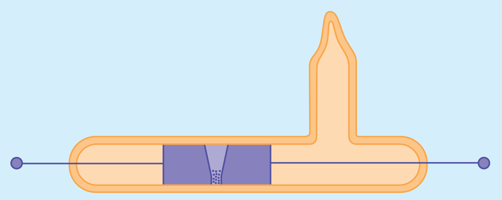

Figure 1. Coherer, Marconi pattern.

exposed to the high-frequency oscillating currents induced by Hertzian waves. All these academics experimented with how far they could separate the coherer from the spark and still perceive an effect and sometimes achieved distances of a few hundred metres. They published and lectured on their work, and even speculated on the possibility of transmitting information without the wires characterizing the contemporary telegraph and telephone systems. But, as successful academics with a range of interests in addition to teaching, they lacked time and motivation to transform 'wireless signalling' from a laboratory curiosity to a business undertaking.

Marconi

This was brilliantly accomplished by a young Italian visitor to the UK named Guglielmo Marconi. He lacked formal scientific qualifications, but single-mindedly applied a natural flair for business and publicity. His method involved demonstrations to public and press, along with promotion of shares in the Marconi Wireless Telegraphy Company. His dramatic lectures (beginning in 1896) included the sending and receiving of a signal between sealed metal cabinets, with the receiving unit being carried by him to various locations in the hall. Marconi was reluctant to disclose 'his' apparatus within the black boxes, but it soon transpired that they consisted of versions of a spark transmitter and coherer receiver.

Marconi's academic predecessors were of course furious, but they had published and the material was in the public domain—he had not stolen the principles, even if he was loath to acknowledge their origins. Presumably he thought this would detract from his business prestige. To this day Marconi remains the 'inventor' of radio in the popular mind.

Not being a scientist, he did not realize that (like light) radio should be line-of-sight, with long distance transmission impossible due to the curvature of the Earth. He simply went ahead and did it! Only later did Heaviside supply the explanation with his reflecting layer in the stratosphere. The subsequent explosive growth of the wireless industry has been extensively documented [3].

A result is that the coherer receiver lasted barely a decade before it was superseded by the more efficient and reliable magnetic, crystal and thermionic valve detectors.

Marconi's coherer

Marconi improved the coherer of Branly and Lodge by using a 5 mm bore glass tube containing a *small* quantity of nickel filings mixed with 4% of silver filings and a trace of mercury. The particles were held loosely between solid silver electrodes. An example used in his early public demonstrations is shown diagrammatically in figure 1 and the actual device is now conserved in the Museum of the History of Science, Oxford [4]. It will be seen that the opposing faces of the electrodes are bevelled, so that the gap containing the filings (and so the packing density of the latter) could be adjusted by rotating the tube around its axis. Platinum wires leading from the silver electrodes were fused into the glass, and the tube was evacuated and hermetically sealed to prevent the entry of moisture, oxygen and sulfurous gases with the risk of tarnishing and corrosion.

Demonstrations

Simple coherers

Marconi tried to give the impression that the construction of a coherer was a complex and delicate operation requiring much skill and experience. It is not: they are easy to make [5, 6]. One general pattern is shown in figure 2.

The ends of two M5 steel screws are first filed flat to remove any plating, grease etc and then bevelled as shown. One screw is thrust halfway into a 30 mm length of 5 mm bore clear vinyl tubing and the assembly clamped in a vertical position. Filings are made by holding a piece of a chosen metal—an ordinary iron nail makes a good beginning—in a vice, positioning a sheet of clean paper on the bench beneath it. File with a clean (preferably new) '8 inch' medium file, making downward strokes. A few minutes work should

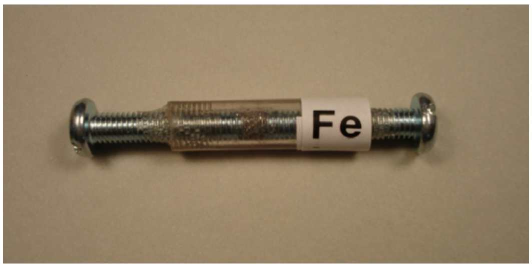

Figure 2. A simple coherer.

produce sufficient filings. Fold the paper in two, open out and gather the filings in the crease. They may then be carefully funnelled into the open end of the plastic tube, forming a layer about 0.5 mm deep on the screw. Insert the second screw and push it in until compression of the filings prevents further motion. Then pull it backwards until there is a gap of about 1 mm between the screws and the filings have a free surface when the coherer is horizontal.

Testing may be accomplished with an inexpensive digital multimeter[1] using the test leads provided to clip it to the screws of the coherer (figure 3). Set to the 200 kilohm (200 kΩ) range. A resistance of at least 10–20 kΩ should be displayed: if not, adjust the spacing of the screws and rotate the coherer. It is possible to have too many or too few filings—adjust accordingly. The indicated resistance will probably not be completely stable, but should remain at a high value. Now produce a pulse of radio waves from the spark source described below. The resistance of the coherer, as indicated by the digital meter, should immediately drop off the high resistance scale. Gentle manipulation of the range dial (so as not to disturb the coherer) should give a resistance measured in tens of ohms—an increase in conductivity of three orders of magnitude. Tap the coherer gently with a pencil, whereupon its resistance should return to a high value, although not necessarily the original figure. Triggering of the spark source should again restore the low resistance cohered condition: the cycle is repeatable indefinitely. Nowadays the coherer would be termed a bistable device. If all is well, rings of cellulose cement may be applied where the screws enter the plastic tubing. The pioneers did not, of course, have the benefit of a high resistance meter when setting-up their devices: they had to proceed by trial-and-error or, at best, by noting the deflection of a mirror galvanometer produced by a cell connected in series.

Figure 3. Testing of the simple coherer with a digital ohmmeter.

See how far away you can stand to operate the sparker and cause a significant drop in resistance. I found about 3 m with this simplest set-up, where the receiving antennae were simply the leads to the digital meter. Increasing distance causes a lower degree of coherence, so the ratio of ‘uncohered’ to ‘cohered’ resistance diminishes.

A safe spark transmitter

Marconi and other pioneers employed commercially made induction coils capable of producing sparks 15 or even 25 cm long. These are obviously out of the question in any school or public situation. However, all that is needed for a modest demonstration is an electric spark, and these are readily and safely produced by an inexpensive piezoelectric percussion igniter, as used in camping stoves and gas barbecues [7]. One may be purchased new on the Web[2], and comes

[1] Maplin ‘Domestic’ digital multimeter N20AX, at £6.99 plus post and packaging. This measures microamps and megohms as well as the more usual scales. (Google ‘Maplin Electronics’ for more information.)

[2] Search for *gas igniter* on e-bay. A new 18 mm diameter piezoelectric type, complete with 75 cm PTFE insulated flexible cable, is listed at £4.90 plus post and packaging.

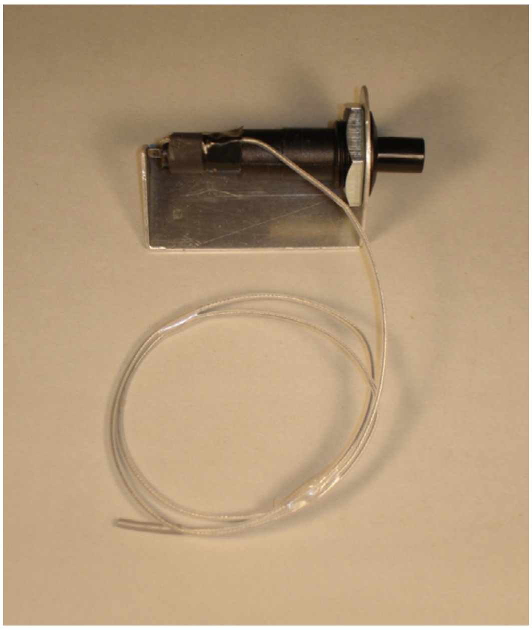

Figure 4. A piezoelectric spark transmitter.

complete with 75 cm of PTFE insulated cable fitting the tag at the end of the igniter. Saw off a few mm of the black plastic surrounding the tip of the central electrode, cut the connectors from the cable, bare 10 mm of the internal wire at one end and twist firmly around the exposed electrode. Insulating sleeving may then be shrunk around the joint and the far end of the cable. An aluminium holder enables the igniter button to be pressed with the cable—now acting as an aerial—hanging down, a spark jumping the gap (<1 mm) between electrode and holder (figure 4). A short spark is more efficient than a long one [8].

My prototype did not affect TV or radio reception when operated in their vicinity. The voltage involved is not dangerous, although it can be felt when the central electrode is pressed against the skin. Indeed, devices of this nature are sold for the self-treatment of arthritis!

Aerial and earth

Marconi's important addition to both transmitter and receiver was a vertical wire connected to one side of the spark gap and the coherer. He called it an *aerial* or *antenna*. We have already attached one to the piezoelectric spark source. Another may be constructed for the coherer receiver described above from a 50 cm length of heavy wire cut from the straight section of a wire coat hanger. Thrust it vertically into a hole drilled in a block of dry wood and, for safety, push a cork on the upper end. Connect the lower end to one side of the coherer shown in figure 3, using a short length of flexible insulated wire fitted with crocodile clips at its ends. I found the range at which the sparker caused coherence to be increased to 5 m with such an aerial.

Marconi also introduced the idea of *earthing* the opposite end of the coherer with a wire connected to a buried copper plate or water pipe. I tried the latter and achieved an increase in range to 7 m. The body of the experimenter acts as a 'virtual earth' for the spark transmitter described above. A flexible cable attached to the aluminium holder was tried and appeared to increase the range by a meter, but the benefit was negated by the awkward trailing cable.

Alternative metals

Other metals may be reduced to filings and loaded into further coherers. They are so easily and cheaply made that, rather than dismantling the first, it is better to construct and store additional devices for future use and investigation. I tested aluminium, brass, copper, graphite, silver, stainless steel and zinc. All worked (as found by Branly in 1890) but aluminium, copper and graphite appeared somewhat more mechanically sensitive and difficult to maintain in a very high resistance condition than the 'standard' iron coherer. I did not test relative ranges or try mixtures of two or more metals.

Visible indication

A 3 V battery and light-emitting diode (LED (see footnote 1)) may be added to the basic circuit as shown in figure 5. The polarity of the battery relative to the LED must be noted, while the 100 Ω resistor protects the latter against accidental excess current. The meter may be left in place, its readings being helpful in the initial stages of adjustment.

It was found that the LED glowed brightly at sparker distances up to 7 m, although the 'cohered' resistance was greater as separation increased.

At 8 m the cohered resistance was about 75 kΩ and the LED was noticeably less bright. At

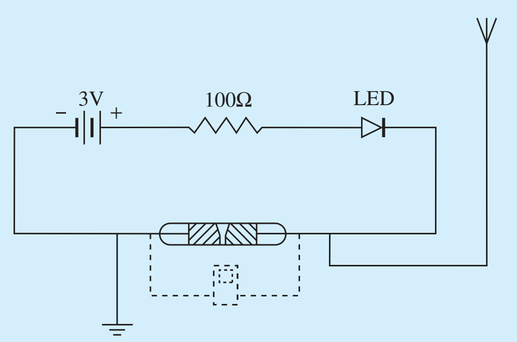

Figure 5. Circuit combining a coherer with a LED.

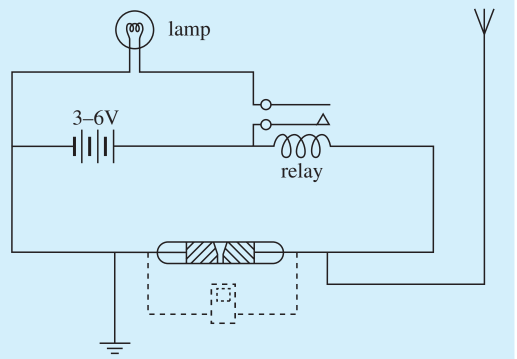

Figure 6. Circuit combining a coherer with a relay.

9 m it was dimmer still and at 10 m no response was obtained. Two or three sparks might produce sufficient conductivity to light the LED brightly at the longer separations.

It will be realized that, once triggered, the LED will remain on indefinitely so long as the coherer is not disturbed.

Use of a relay

An electric bell or buzzer will probably require more current than is readily passed by the coherer. The solution is to incorporate a sensitive reed relay (see footnote 1) as shown in figure 6. (Many nominally 6 V relays will work with 3 or 4.5 V, but 6 V gives a more positive action.) The relay contacts may be used to connect a torch bulb, buzzer or other apparatus. Again, these devices will remain activated until the coherer is mechanically disturbed.

Continuous sensitivity

Marconi wanted his coherer to react to the ‘long’ or ‘short’ signals comprising the Morse code already familiar to telegraphists. Activating the primary of an induction coil for long or short periods with a standard key would produce long or short trains of radio waves, but the simple coherer would react only once at the commencement of an incoming signal, be it of brief or extended duration.

He therefore arranged that the hammer of an electric bell (connected via a relay) would, upon detection of a signal, lightly strike the coherer and restore it to its ‘high resistance’ state. The result was that the coherer remained conductive for so long as a signal persisted, but turned off as soon as a pulse ceased. However, a complication was that sparks at the make-and-break of the bell caused false signals. It was found necessary to add air-cored coils (known as ‘chokes’) in series in the bell circuit to prevent this interference. The continuously sensitive system enabled Morse code messages to be received, working a printer as well as giving audible signals in earphones worn by the operator.

Electric bells are difficult to obtain nowadays, but securing the coherer with adhesive tape to a miniature 3 V dc permanent magnet motor (as used in toys and gadgets) makes an effective substitute. Chokes must still be fitted if sparks at its commutator are not to cause interference. Even then, the problem of sending ‘dashes’ remains, for there appears to be no safe and legal alternative to the induction coil. The simplest solution is to have someone tap the coherer with a pencil as soon as a visible signal is noted, and devise a signal code based on receiving a certain number of flashes generated by sequential operation of the spark transmitter.

Mechanism of the coherer

It has been mentioned above that the coherer was applied to wireless telegraphy for only a comparatively limited period and with its demise research on its mode of action was diverted to its successors. However, it was suggested that the abrupt rise in conductivity following a high-frequency pulse was due to ‘micro-welding’ at multitudes of poor contacts within the filings, these being broken once again as soon as the device was disturbed. More recently, it has been wondered whether semi-conductive phenomena in oxide films surrounding the metallic grains might be responsible. The problem is now being taken up again, appropriately in France.

It seemed to me that the behaviour of filings of the inert noble metals might offer a clue to distinguish between these proposals. I therefore made coherers with filings of gold and platinum, and tested them as above. Both worked satisfactorily, being comparable with iron and other metals. The noble metals do not form films of oxide on their surfaces, so this finding would support a mechanism involving some form of micro-welding. The same conclusion has been reached from another direction by Falcon and his co-workers [9].

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Allan Mills retired 12 years ago from the post of Senior Lecturer in Planetary Studies at the University of Leicester, UK. Nowadays, it is difficult to undertake home- or school-based research at the cutting edge of science, but he has found that a wide field remains unexplored in the history of science—particularly quantitative and experimental aspects. This article demonstrates how early radio still holds some intriguing questions that lend themselves to practical investigation by school or college students.