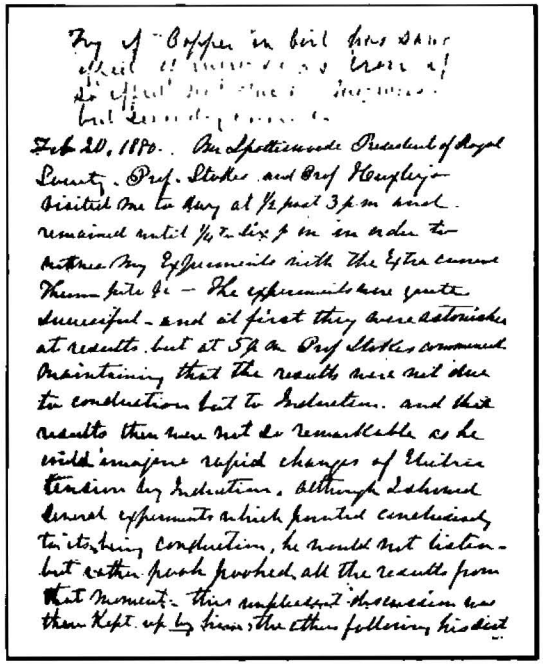
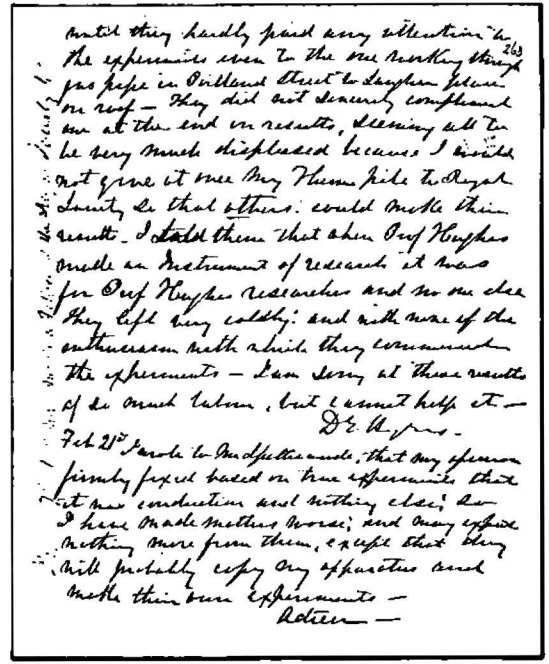


Feb 20, 1880. An Afternoon at President of Royal Society. Prof. Stokes and Prof Huxley visited me to day at ½ past 3 p.m and remained until ½ to six p.m in order to witness my Experiments with the Etheric Current Theory &c — The experiments were quite successful - and at first they were astonished at results but at 5 p.m Prof Stokes announced Maintaining that the results were not due to conduction but to Induction. and that results then were not so remarkable as he would imagine rapid changes of Electric tension by Induction. although I showed several experiments which pointed conclusively to its being Conduction, he would not listen - but rather provoked all the results from that moment - this unpleasant Conclusion was then kept up by him, the other following his lead



until they hardly paid any attention to the experiments even to the one working through gas pipe in Pall Mall Street to daylight future on roof — They did not sincerely compliment me at the end on results, seeming all to be very much displeased because I would not give it over my House like to Royal Society so that others could make their results. I told them that when Prof Hughes made an Instrument of research it was for Prof Hughes researches and no one else they left very coldly: and with none of the enthusiasm with which they commenced the experiments — I am sorry at these results of the Council taken, but I cannot help it —

D E Hughes.

Feb 21st Spoke to Mr Spottiswoode, that my opinion firmly fixed based on true experiments that it was conduction and nothing else; that I have made Mathers House; and many experiments more from them, except that they will probably copy my apparatus and make their own experiments —

Adieu —

Frontispiece ***Two pages from the notebook of Professor D.E. Hughes describing the visit of the Fellows of the Royal Society to his laboratory***

Note the comment added later in the margin — 'June 7 188(?) was made a fellow of the Royal Society!'

Early radio wave detectors

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For Diana, Hywel and Cenydd

Contents

		Page
	Preface	*ix*
1	Introduction	1
2	Improved spark-gap detectors	10
3	Coherers	18
	Restoration of coherers	38
	Self-restoring coherers	50
4	Electrolytic detectors	65
5	Magnetic detectors	85
6	Thin-film and capillary detectors	125
7	Thermal detectors	150
8	Tickers, tone-wheels and heterodynes	172
9	Miscellaneous detectors	188
10	and so to the modern era	205
	Select bibliography	
	References	

Preface

When I was a student at Imperial College, Third Year Honours students had to write an essay and deliver a short lecture on any subject of their own choice. I elected to give a lecture on early radio detectors, my interest in this topic having been awakened by reading the Science Museum *Handbook of Radio Communication* published in 1934. This interest continued after graduation, and over the years I have built up a set of references and given lectures under the auspices of various societies and institutions. It was after such a lecture, given at the Institution of Electrical Engineers Annual Conference on the History of Electrical Engineering at Manchester in 1975, that Dr. Brian Bowers and Mr. Keith Geddes made the suggestion that I might care to write a booklet on the subject for the Science Museum. It is from this suggestion that the present book has grown.

I am very grateful to the Director of the Science Museum for allowing me the privilege of being Visiting Research Fellow from February to September 1977, and to the Council of University College Swansea for granting me a period of sabbatical leave in order to take up this appointment. During this leave the burden of my laboratory duties and my tutorial classes was cast on my colleagues in the Department of Electrical and Electronic Engineering, and I am grateful to them for carrying this extra load.

Living away from home and travelling frequently to London is an expensive business, and I am indebted to the Science Museum for covering certain of the travelling costs, and to the Leverhulme Trust who awarded me a research grant to help defray expenses. My wife's fortitude in coping alone with the children in my absence was also a major factor in enabling this work to be undertaken.

It is a particular pleasure to acknowledge the assistance and kindness of the staff of the Science Library, South Kensington, who, with unfailing cheerfulness, helped me to chase up many of the obscure references containing the information on which this book is based. I am also very grateful to Keith Geddes, who read the manuscript and made numerous comments and suggestions for improvement.

I hope that other electrical engineers will find the subject as fascinating as I have, and that the rediscovery of some of the 'lost' phenomena described will remind them of the tremendous achievements of our founding fathers. The writer on the history of radio has one thing in common with the medieval historian: just as the lance is no longer used in warfare, having been rendered obsolete by later developments, so have many of these phenomena sunk into obscurity. Indeed, many of them have never been satisfactorily explained, and authors of the period often leave out of their accounts what we would nowadays consider to be vital information. One hazard, however, not shared with the medievalist is that it is quite possible for people who may have had first-hand experience of these matters to be with us today. If a mere stripling of forty odd years has got it wrong through lack of such experience, I crave their indulgence in advance.

Vivian J. Phillips
Sketty Green
Swansea, Wales

July 1978

Acknowledgments

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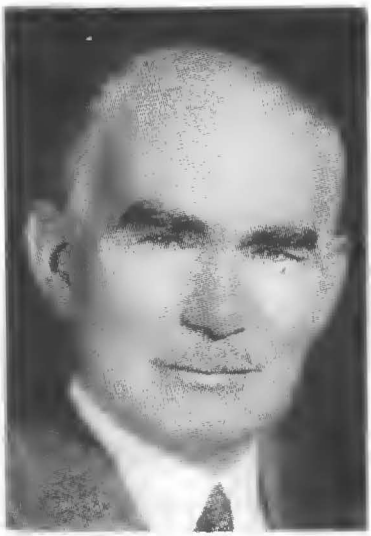

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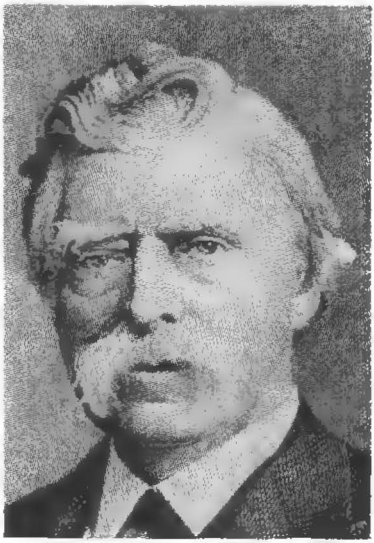


David Edward Hughes 1831–1900

Heinrich Rudolph Hertz 1857–1894

Edouard Branly 1844–1940

Introduction

Mankind has been endowed with the five senses of sight, hearing, touch, smell and taste. It is not surprising, therefore, that his scientific curiosity was aroused from the earliest times by the light he could see, the sounds he could hear and the heat he could feel. Although the physicist has rather neglected the senses of smell and taste, these too have received their share of attention from people with gastronomic interests and from those concerned with the manufacture of perfumes.

There are, however, many phenomena in nature which cannot be perceived directly, and these must be converted into a form appreciated by the senses before their presence is revealed. Thus a magnetic field must be rendered visible by the controlled swinging of a lodestone or the pattems of iron filings, and an electrostatic force must create visible sparks, audible cracklings or unpleasant shocks before we are aware of its presence. For this reason radio waves lay undiscovered until the nineteenth century although they had always been produced naturally during thunderstorms. During that century various scientific workers became aware that there was some unknown phenomenon which was causing inexplicable results in some of their experiments.[1] For example, in 1842 Professor Joseph Henry noticed that the discharge of a Leyden jar (the form of capacitor used in those days*) was able to magnetize needles situated in the basement thirty feet below although two fourteen-inch thick ceilings intervened.[2] He also noticed that lightning flashes seven or eight miles distant produced a similar effect. Again in 1875, Professor Elihu Thomson was using a sparking coil in a room on the first floor of the Central High School in Philadelphia. He

*The 'jar' was used as a unit of capacitance, and the Admiralty Handbooks continued to quote the conversion factor for jars to microfarads until well into the 1930s. J.A.Fleming stated in his book (Section 2, Reference 6) that the pint size jar had a capacity of about 1/700 μF and the gallon size 1/300 μF.

had connected one side of the spark-gap to earth and the other side to a large insulated metal can, and he discovered that when he held a sharp pencil point to a brass door-knob about a hundred feet away at the top of the building, small sparks could be seen each time the sparking coil operated in the room below.[3,4] In a paper written years later he recalled his experiences on this occasion and described an improved spark detection apparatus which was designed for him by Thomas Edison.[5] This consisted of two sharpened points forming a small spark gap contained in a dark box, which made it easier to observe the feeble secondary spark.

Perhaps the best documented of all these early observations were those made by Professor D.E. Hughes in London between 1878 and 1880.[6–9] Professor Hughes (who was actually a professor of music) had been experiencing difficulty in balancing an inductance bridge with which he was working (Fig. 1.1) and he eventually traced the trouble to a loose connection in the circuit. As it happened, he was also experimenting with some of his primitive microphones in the same laboratory. One of these microphones consisted of a steel needle lying in loose contact with a piece of coke, the whole being connected in series with a battery and a telephone earpiece. (Other types of loose-contact microphones such as those of Fig. 1.2 were also used by him.) Sound vibrations impinging on this microphone would vary the contact resistance and hence the current, thereby reproducing the sound in the earpiece. Hughes noticed that when the faulty contact on his bridge was made and broken this created noises in the earpiece even though the two sets of apparatus were far apart and unconnected in any way. He was quite excited by this discovery and went on to carry out many experiments,

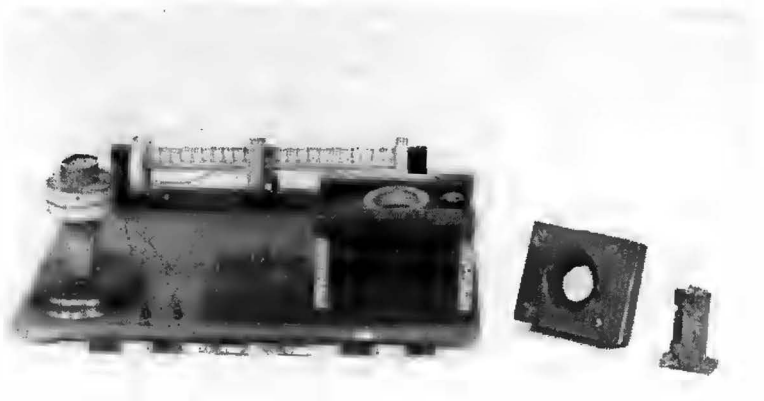
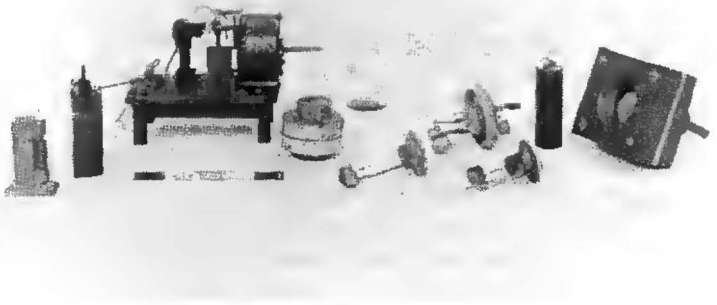


Fig. 1.1 *Hughes's induction balance circuit*
[Science Museum photograph]



(*a*)

(*b*)

Fig. 1.2 *Hughes' microphone detectors*
(*a*) selection of detectors
(*b*) steel-needle/coke detector in glass jar. The clockwork device at the right (also seen in (*a*) above) was an automatic interrupter to allow experiments on reception at a distance without need for an assistant to operate the transmitter

including the reception of signals in the road outside his house in Great Portland Street. He showed his results to various people, and on 20th February 1880 he arranged a demonstration for the President and several Fellows of the Royal Society. In spite of the clear success of the

demonstration and the visitors' initial favourable reaction, they eventually declared that the results could be explained by known electric and magnetic phenomena and were in no way a proof of the existence of the electromagnetic radiations which James Clerk Maxwell, the Scottish physicist, had predicted in his theoretical studies of 1864. The frontispiece shows the pages of Hughes' notebook in which he recorded his experiences on this occasion. Such eminent scientists having pooh-poohed his work, Hughes did not venture to publish it until many years later, but his notebooks (kept in the British Museum) illustrate the range of experiments which he carried out and establish his claim to be one of the pioneers of radio science.

It was in the years 1886–88 that the German Heinrich Hertz put the whole subject of electromagnetic radiations on a firm footing in a series of classic experiments which established beyond all doubt that these 'aetheric radiations', which we now call radio waves, most certainly did exist and that they possessed properties similar to light waves in that they could be reflected, refracted, polarized etc.[10] The transmitting apparatus which Hertz used is shown in Fig. 1.3. It consisted of two small metal balls forming a spark-gap connected across the terminals of a sparking coil (or 'inductorium' as it was sometimes called). To each ball was attached a rod connected at the outer end to a large metal plate or sphere. The whole thing formed a capacitor which was charged up by the high voltage produced by the coil. When this voltage became sufficiently high a spark occurred across the gap so that the two plates of the capacitor were effectively connected together via the rods, which possessed the property of inductance. It is now well understood that in such circumstances the resulting current which flows is oscillatory in nature, the charge surging to and fro between the plates. In the early nineteenth century the possibility of such an oscillation was the subject of much debate and dispute, but the experimental work of Henry and others, coupled with the theoretical studies of William Thomson (later Lord Kelvin) established beyond all doubt that oscilla-

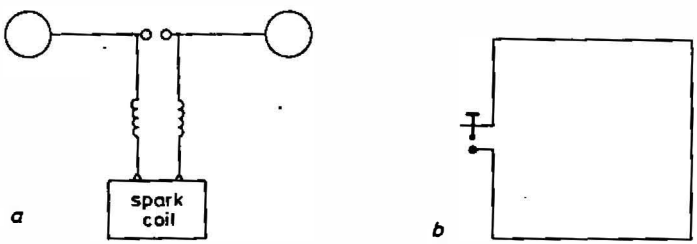


Fig. 1.3 *Apparatus used by Heinrich Hertz in his classic experiments of 1886-88* (*a*) Spark transmitter, (*b*) spark-gap detector or 'ring resonator'

tions could occur.[11] In Hertz's apparatus the oscillating flow of charge set up electric and magnetic fields which caused the emission of radio waves. It is perhaps interesting to note in passing that the oscillation was often at a frequency of 80–100 MHz. in what we would now call the v.h.f. range, although this varied greatly with the dimensions of the apparatus used. The experiments were carried out over distances of a few metres only.

Hertz's radiation detector, often referred to in the literature simply as his 'resonator', is also illustrated in Figs. 1.3 and 1.4. It consisted of a square or circular ring of wire broken at one point to form a small spark-gap. When it was subjected to the radiations from the transmitter a minute spark could be observed at this gap. A micrometer screw arrangement was usually provided so that the width of the gap could be adjusted for optimum results. Some experiments subsequently performed by Sir J.J. Thomson and Mr. Peace at Cambridge showed that in order to produce a visible spark between two metal balls, a potential difference of at least 300 V was needed.[12] Thus it will be appreciated that this spark-gap detector was a very insensitive device indeed and it is a tremendous tribute to Hertz that even with this crude apparatus he was able to demonstrate all the effects previously mentioned. There is some evidence to suggest that Hertz also used another form of receiver consisting of a spark-gap and rods identical to those at the transmitter,[13] but on the whole he seems to have preferred the ring form of Fig. 1.3.

It was soon quite clear to all that before any further serious work could be done on this subject it would be essential to find some better means of detecting the presence of radio waves. Many physical phenomena, some long since forgotten, were pressed into service for this purpose and a great deal of ingenuity was shown in the very best 'string and sealing wax' traditions of experimental science. This book is a compendium of such techniques and its purpose is to tell the story of the search for better detecting devices and to illustrate the inventiveness and skill of the founding fathers of radio science.

Before embarking on the story, it would perhaps be useful to say a word or two in general about the development of radio. In the first decade or so after the work of Hertz it was largely a matter of investigating a new phenomenon in the laboratory. The verb 'to detect' is defined in Collins' *New Gem Dictionary* as 'to find out or discover the existence or presence or nature or identity' of something, and this describes exactly the purpose of the experiments which were conducted at that time and the function of the various types of receiving devices which were developed. Alternative names for these detectors

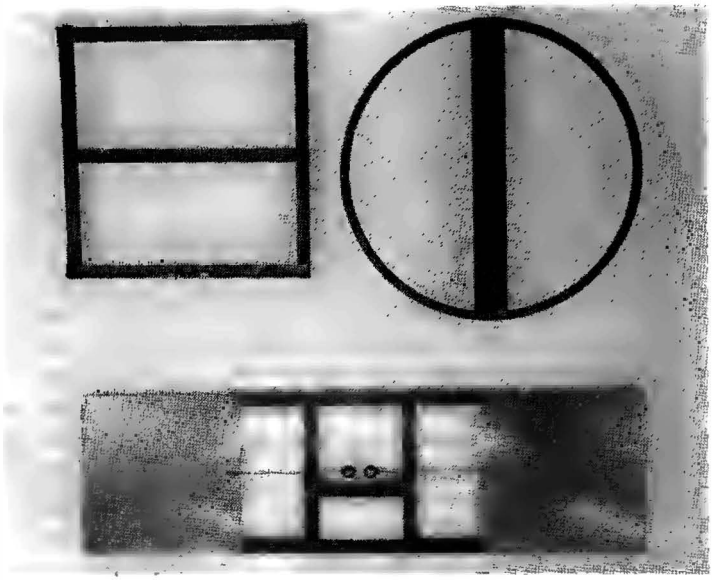


Fig. 1.4 *Experimental apparatus used by Heinrich Hertz in his work on radio waves (replica)*
[Science Museum photograph]

occasionally encountered in the literature before the terminology became standardised are 'wave responders', 'revealers' and cymoscopes' (from the Greek *cyma*, a wave, and *skopein*, to see).

It was later realised that these new 'Hertzian waves' might well be useful for wire-less telegraphy, that is to say, for the transmission of Morse signals to distant places without the need for a wire connection. The reception of a Morse-type radio signal of dots and dashes separated by periods of silence really amounts to detecting whether or not a signal is present in the receiving aerial at any particular time, and so the word 'detector' was still very appropriate for the device which performed this function. Somewhat later, the techniques of amplitude-modulation were introduced, enabling speech to be transmitted directly by wireless telephony. The pieces of apparatus which recovered the speech signal from the radio carrier at the receiver were really the direct descendants of the wireless telegraphy 'detectors' and the word 'detection' continued in use to describe this operation until it was replaced by the better term 'demodulation' in quite recent times. The old word, though, is even now in the current vocabulary of the radio engineer,

and he still refers to the 'envelope detector' and the 'ratio detector'. The radar engineer actually uses the word in a sense which is very near to the original meaning, implying discovering the existence of something.

Over the years, there were naturally developments on the transmitting side, too.[14] The original Hertzian transmitter generated isolated pulses of damped radio-frequency oscillation, these pulses occurring at more-or-less irregular intervals depending on the exact instants of sparking across the gap (Fig. 1.5*a*). If the detector happened to be a device which converted each pulse into a clicking sound in a telephone receiver the signal would be heard as an irregular buzzing sound. In a later development several spark-gaps were mounted on a rotating wheel which caused the sparks to occur at definite regular time intervals so that the received sound was a distinctive musical note which could be perceived more clearly in the presence of interfering signals. This was the so-called 'musical spark' form of transmission (Fig. 1.5*b*). There was a further advantage with this mode of operation. The spark-gap was connected in a primary circuit which was mutually coupled to a tuned secondary aerial circuit. During the spark, energy was transferred to the secondary. The motion of the electrodes quickly extinguished (or 'quenched') the spark, open circuiting the primary side. The transferred energy was then dissipated usefully in the aerial, none

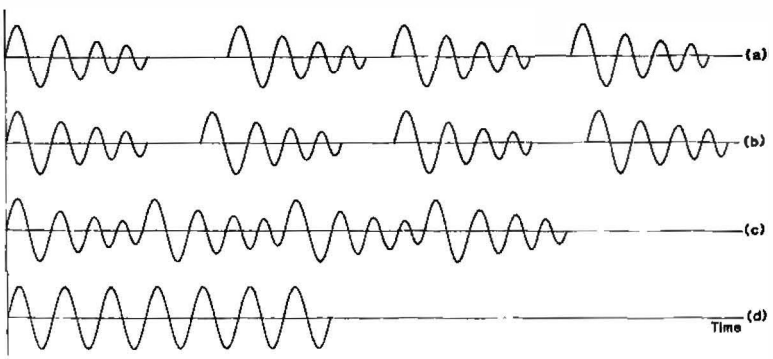


Fig. 1.5 *The transition from simple spark transmission to the continuous radio-frequency carrier (note that there would be many more cycles of r.f. oscillation within each burst than can conveniently be shown on a diagram of this sort)*

(*a*) Isolated irregular sparks
(*b*) Isolated sparks which occur at regular intervals; the 'musical spark' form of transmission
(*c*) Timed spark transmission. Here the phases of the separate bursts of r.f. are controlled so that they merge without gross discontinuities
(*d*) A continuous carrier

being retumed to the primary circuit.

For various practical reasons it was very desirable to get away from this pulsed form of signal and to produce a continuous high-frequency carrier instead. If the individual bursts or pulses of Fig.1.5*b* were to be spaced more closely and with the correct phase, they could be made to run smoothly into each other producing an almost continuous signal such as that in Fig.1.5*c*. This was the 'timed spark' form of transmission A further development was the production of a truly continuous sinusoidal signal (Fig. 1.5*d*) either by generating it directly with a high-frequency alternator (producing long waves with frequencies in tens of kilohertz), or else by an arc transmitter which made use of the negative resistance of the carbon-arc to overcome the damping in a tuned circuit, thereby enabling it to oscillate continuously. Finally, the thermionic valve arrived on the scene to provide a convenient and easy method of generating a sinusoidal r.f. signal.

This book will cover a period extending from Hertz's experiments up to the coming of the crystal detector and the valve, which events may be considered as taking radio into the modern era. It must be appreciated, however, that even after the invention of the thermionic diode and triode (in 1904 and 1906-7) many other types of detector were still in use well into the Great War of 1914-18,[15] and it was not until the 1920s that the victory of the valve was complete.[16] Modern electrical engineers have often been brought up to believe that *rectification* is the basis of all radio detectors, but it is worth making it clear at the outset that most of the detectors to be described in this book were *not* rectifiers; they were instruments for indicating the presence or absence of a radio-frequency signal and, as we shall see, they used all sorts of varied phenomena. Rectification as a *means* of detection arrived at a comparatively late stage with the crystal and the diode.

Most of the detectors to be described were, by their nature, only able to provide a simple yes/no indication of the presence or absence of a received signal. A few were able to give a quantitative measure of the strength of that signal, but most of these were unable to operate with sufficient speed to follow the dots and dashes of a telegraphy signal. It will also be appreciated that they did not all perform their function equally well. Some were excellent, reliable and positive in action, while others were temperamental and (quoting one contemporary writer on the subject[17]) 'they occasionally exhibit very tricky antics'! Very few indeed progressed beyond the laboratory stage to see active service in practical communication systems. Those that were successful in this respect will be noted particularly, and some comparative figures will be considered in the final chapter.

ABOUT THE AUTHOR

Dr. Vivian J. Phillips received his early education at the Gnoll School and the Grammar School for Boys, Neath, Glamorganshire. He was awarded a State Scholarship to study at Imperial College, London, where he graduated with first class Honours in 1955. After research undertaken at the same college he was awarded the degree of Ph.D. for a thesis concerned with the frequency variations within the envelope of single-sideband modulated speech signals. After a short period spent in an industrial research laboratory he became Assistant Lecturer in the Electrical and Electronic Engineering Department of the University College of Swansea, a constituent college of the University of Wales. He is now Senior Lecturer there, and he has also served as an elected member of the college Senate and as Warden of one of the Halls of Residence. In 1977 he spent a period of sabbatical leave at the Science Museum, South Kensington as Visiting Research Fellow where he continued his researches into early radio detectors, in which he has maintained an interest since writing an undergraduate dissertation on the subject. He has contributed a paper on magnetic detectors to the Proceedings of the IEE, and he has been a regular contributor to the annual IEE Weekend Meetings on the History of Technology. Dr. Phillips is married with two sons, and includes caravanning and heraldry among his hobbies.

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