It all started 100 years ago with Heinrich Hertz

We take today's technological wizardry for granted and enjoy the benefits of satellites, radio, TV, and other marvels as if they all fell from Heaven. But they did not! Their story is often dramatic and awe-inspiring. Here is a brief homage to one of the great pioneers who made it all possible.

by PAUL GRAD

About 100 years ago, a series of experiments were conducted in the German city of Karlsruhe. They turned out to be among the truly epock-making experiments in history. The man who performed them was a 30-year-old, recently married physics professor named Heinrich Rudolf Hertz, and he caused a great international sensation at the time.

With the experiments, Hertz conclusively demonstrated the existence of electromagnetic waves and showed several of their main properties. Most sensational was his demonstration that electromagnetic waves exhibited many of the main properties of light, already well-known at the time.

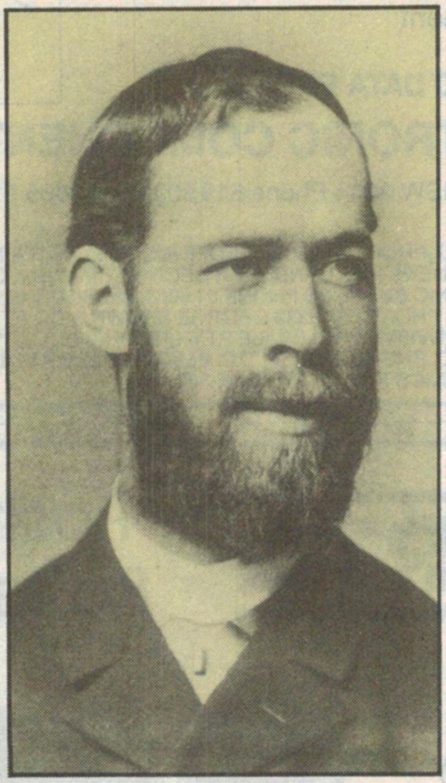
He thus gave experimental confirmation to the theory of electromagnetic propagation, which had been published about 25 years earlier by the Scottish physicist James Clerk Maxwell.

Maxwell's theory had predicted that electromagnetic radiation propagates with the speed of light, suggesting that light is itself a form of electromagnetic propagation. This was seen as extraordinary by his contemporaries, because hitherto electromagnetism and optics were considered to be separate fields.

The scientific world had to wait almost a quarter of a century before Maxwell's predictions were proven correct.

It is difficult, today, to appreciate the dramatic impact Hertz made with the announcement of his experimental results he caused the international scientific community to be ablaze with excitment. He became famous and received many honours.

A lot of water has flowed under the bridge since those days, as we all know, and Hertz' name has lapsed into comparative obscurity. His importance and stature as a scientist do not seem to be fully appreciated today.



Heinrich Hertz

Who was Hertz, what was the measure of his achievements, and why is he now an only vaguely remembered figure?

Hertz was born in Hamburg in 1857 and studied initially to become an engineer at the Dresden Technical College. He interrupted his engineering studies, however, and volunteered for military service.

After about one year of military service he decided to abandon engineering. Instead, he studied physics and mathematics at the Technical College and at the University in Munich. In 1878 he went to the University of Berlin, attracted by Helmholtz and Kirchhoff, two of the greatest scientists of the time.

Both Helmholtz and Kirchhoff constituted a special attraction to students of mathematics and physics. Hertz thus did what all serious and ambitious students do, and followed the masters. He became Helmholtz' assistant in 1880.

His interest in electromagnetism seems to have been first aroused in a serious way during his times in Berlin. Here he started to perform both experimental and theoretical work on various problems of electromagnetism.

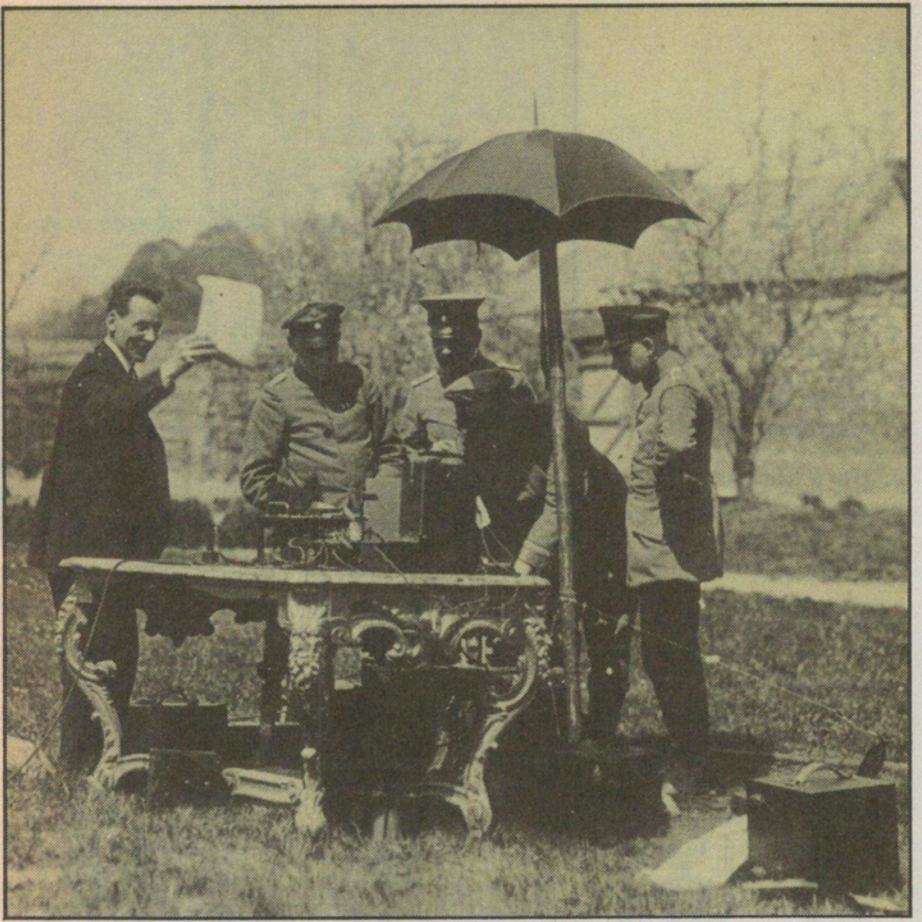
He received a doctor's degree from the University of Berlin in 1880, "magna cum laude", which was a rare accolade in Berlin those days. His thesis work departed from previous work by the French physicist Arago on the mutual effect between magnets and copper plates moving relatively to each other. It examined the case of a conducting sphere, rotating around one of its own diameters in a magnetic field. He calculated the patterns of propagation, on the sphere, of the currents induced by the magnetic field as well as the mutual effect between the magnetic field and the sphere. He performed investigations using both a solid and a hollow sphere.

From Berlin he went to Kiel, where he stayed about two years, during 1883-84. He was not happy there, however, and in 1885 he accepted an offer of a professorship in physics from the Technical College at Karlsruhe.

We don't know when he first thought of attempting to verify Maxwell's predictions, but it was here in Karlsruhe that he performed those great experiments, publishing his findings in a series of papers between 1887 and 1889.

He moved to Bonn in 1889, having bought the house in which Clausius, a scientist famous for his work on thermodynamics, had lived, and became Clausius' successor at the University there. In the same year, after moving to Bonn, he went to London at the invitation of the Royal Society.

Following his return from London, he



A demonstration, to the German Wehrmacht, of receiving equipment during World War I. (Courtesy of Photo Internationes)

was almost constantly plagued by ill-health. He felt tired and depressed, partly because after his great successes his work appeared to have stagnated, and interest in electromagnetic waves had diminished among scientists.

He performed little additional work of importance and died on New Year's day, 1894, just short of his 37th birthday.

So much on Hertz' short life. Let's now try to convey the magnitude and importance of his achievements.

Maxwell's theory predicted that an electrical disturbance could propagate and produce an effect at a distance from where the disturbance originated.

It incorporated the facts which had already been observed at the time, by Oersted, Faraday and others, that an electric current produces a magnetic field, and that a changing magnetic field (and therefore a changing current) produces an electric current.

However, Maxwell further assumed that those phenomena could propagate in space. He assumed that a changing electric field produces a changing magnetic field in the surrounding space, and this changing magnetic field produces itself a changing electric field, and so on indefinitely, these disturbances propagating in space with the speed of light.

The speed of light had already been accurately measured, but it was not yet known that light is a form of electromagnetic radiation.

Extraordinary as his theory was to his contemporaries, it could not be accepted, like all theory, until experimentally verified.

To understand Hertz' experiments we must look briefly at the special case of an electric current flowing around a closed loop such as a conducting ring.

According to the prevailing view at the time, a current flowing around a closed loop would exert a force on a magnet only at the centre of the loop, but not in the surrounding space. Maxwell, however, assumed that a force would be exerted on a magnet also outside the ring, since a change in the current flowing around the loop would induce an electric field in the space surrounding the loop. And since this electric field would itself be changing, it would induce a magnetic field in the space surrounding the loop.

Also, he assumed that the higher the speed with which the current around the loop changes, the higher will be the intensity (magnitude of the magnetic forces) of this induced magnetic field.

Further, he assumed that the type of material constituting the medium in which the electric field changes, and the medium's dielectric constant, affect the intensity of the induced magnetic field.

Why did it take so long to prove the existence of electromagnetic waves?

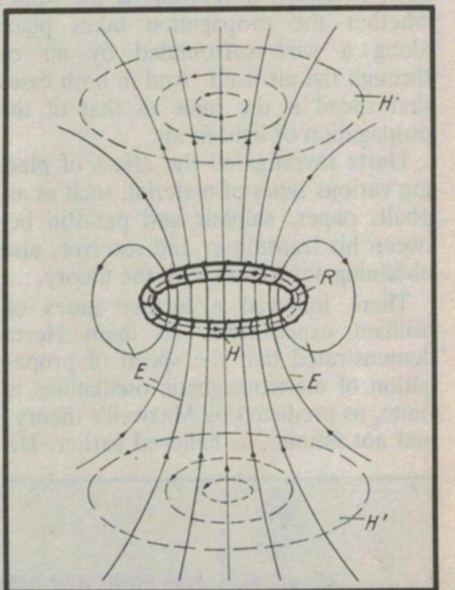
The main reason was that the fastest current oscillations (or alternating current) that could be produced in Maxwell's time — of about 1 million cycles per second — induced magnetic field intensities that were too weak to detect with the means then available.

It is difficult to appreciate, nowadays, how crude were the experimental resources available to scientists 100 years ago. Obviously there were no valves, no semiconductors, none of the paraphernalia of our time, which many of us take for granted. Great ingenuity and inventiveness were required from the researchers, who usually had to build their own experimental equipment from whatever they could find.

How different from today's attitude of many researchers, who keep hooting for more and more funds and better and faster computers!

Naturally, at the time of Maxwell's predictions it was not even known how to cause electromagnetic radiation to propagate or how to detect it in space.

Hertz' manner of solving all these problems revealed an experimental genius of the first order. He showed how frequencies of more than 100 mil-



Electromagnetic field generated by a current flowing around a closed loop.

Heinrich Hertz

lion cycles per second could be obtained.

He used a long straight wire, connected to a conducting sphere on each end, interrupted in the middle by a short air gap. Connecting each of the wire's halves to one of the poles of an induction coil caused sparks to jump across the air gap, and resulted in very rapid oscillations in the wire. Thus he built a crude type of oscillator, equivalent to a crude "transmitter", with a tuned circuit consisting of an inductance and capacitance.

He then built a "receiver" consisting of a circular loop of wire, completed by a short spark gap. The gap was adjustable down to a micrometre by means of a screw. There was also a telescopic viewer attached to the gap to check its exact size.

When this receiver was brought close to the operating transmitter, small sparks jumped across the loop's gap.

With this setup Hertz showed how one could determine the directions of the electrical and magnetic fields produced by the transmitter.

He then calculated the field forces on the basis of Maxwell's theory, obtaining results in full agreement with his measurements.

Hertz also provided another important confirmation of Maxwell's theory. As said earlier, the theory assumes that the induced magnetic field is affected by the medium. The theory also assumes that the speed with which electromagnetic radiation propagates is the same, whether the propagation takes place along a wire surrounded by air or through the air itself. And in both cases that speed is the same as that of the propagation of light in air.

Hertz investigated the effect of placing various types of material, such as asphalt, paper, sulphur and paraffin between his transmitter and receiver, also obtaining agreement with the theory.

There followed a further series of brilliant experiments. In them Hertz demonstrated that the speed of propagation of electromagnetic oscillations is finite, as predicted by Maxwell's theory, and not infinite, as believed earlier. He showed that the electromagnetic radiation does in fact propagate with the speed of light. And he also showed that when reflected upon itself the electromagnetic radiation forms maxima and minima of electric and magnetic field intensity at regular intervals, analogously to the formation of standing sound waves. This was a striking demonstration of the wave nature of electromagnetic radiation.

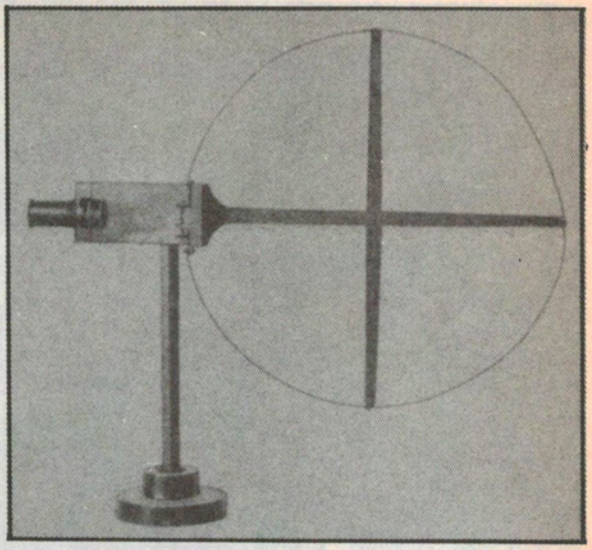
After working with the setup described earlier, Hertz employed a different kind of transmitter, dispensing with the spheres and using a much shorter but much thicker wire. This transmitter produced much more rapid oscillations, with much shorter wavelengths.

Having verified that the electromagnetic waves are reflected from metallic surfaces, he built two large cylindrical mirrors with parabolic cross sections, and placed a transmitter along the focal line of one of the mirrors, and a receiver along the focal line of the other.

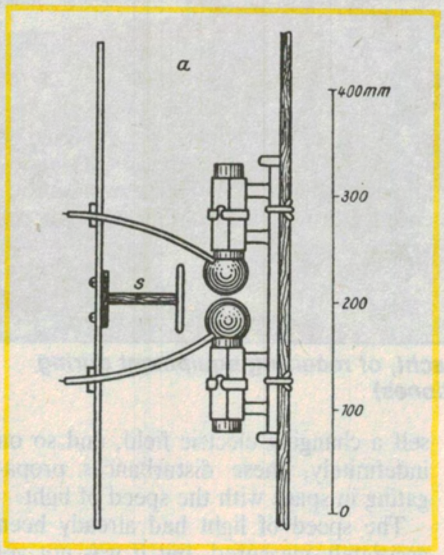
Thus he obtained much higher efficiencies in both transmission and reception, since transmission proceeded in one direction only, and the receiver concentrated the incoming waves in one spot.

With these parabolic mirrors Hertz demonstrated that electromagnetic waves exhibited the, at the time, well-known properties of light, including straight-line propagation reflection, dispersion and polarisation.

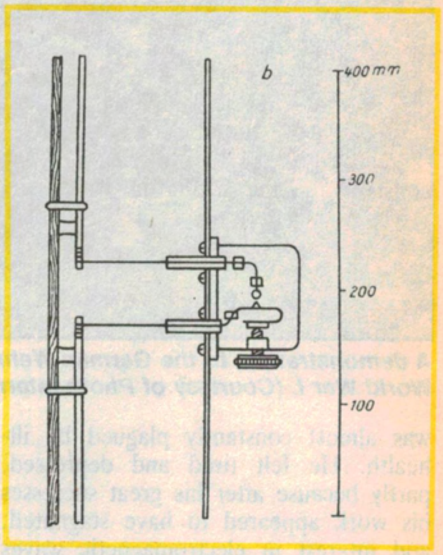
Fancy somebody experimenting with



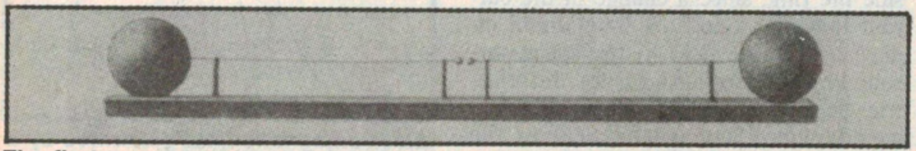
Hertz' first receiver. The loop had a spark gap inside the telescopic viewer on the left.



Hertz improved his transmitter to obtain higher frequencies.



Hertz' improved receiver.



The first transmitter build by Hertz, with which he succeeded in generating 100MHz frequencies, the highest ever produced at the time.

parabolic transmitters and receivers 100 years ago and using them, not only to prove the very existence of electromagnetic waves but also to demonstrate many of their important properties!

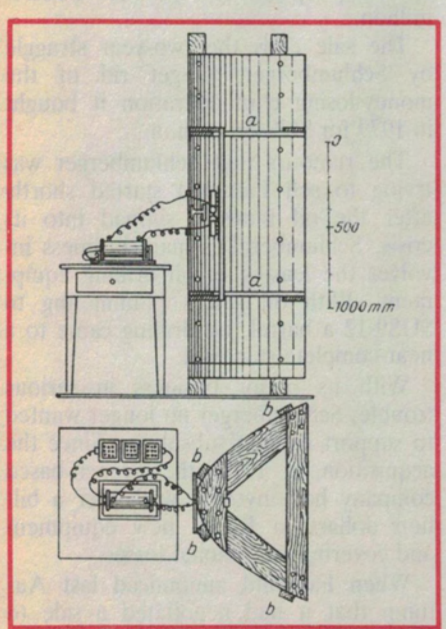
As we can see, Hertz did much more than demonstrate the existence of electromagnetic waves. He was also a pioneer in building and using equipment, and in applying techniques, which are, in principle, quite similar to those used today.

After working with the parabolic mirrors he built a large prism of pitch (the prism had to be large in view of the wavelengths with which he was working), and verified the analogy between the behaviour of the electromagnetic waves travelling through the prism and that of light going through a glass prism.

Hertz caused considerable sensation when he showed that the dispersion of the electromagnetic waves, and their corresponding refractive indexes, agreed very well with Maxwell's corresponding predictions on the basis of the dielectric constants of the media in which the waves propagate.

Always a theoretician as well as an experimenter, Hertz wrote a paper on Maxwell's theory with the intention of providing a simplified and clearer version of the theory. In the paper he extended the theory to the case of moving bodies.

By showing how high-frequency oscillations and electromagnetic waves could be produced, Hertz can be regarded as the founder of wireless communication, even though it was Marconi, as is well known, who first succeeded in transmitting messages telegraphically over large distances.



Hertz built two cylindrical mirrors with parabolic cross sections.

He also seems to have been the first to observe the photoelectric effect. In his experiments he saw that a spark gap released sparks much earlier when the gap was illuminated by ultraviolet light originating from another spark gap, which was a very surprising phenomenon at the time.

An interesting and little-known work of Hertz', and quite independent of his research on electricity, is a book called "Principles of Mechanics", in which he attempted to develop a theory of mechanics without using the concept of "force". His effort in this field is highly original and consistent, but has not proved directly fruitful.

His work on electromagnetism and his "Principles of Mechanics" were well-known to a later scientist named Albert Einstein. Before developing his relativity theories Einstein carefully studied the works of people like Helmholtz, Kirchhoff, Mach and Hertz. We don't know to what extent Hertz' work influenced Einstein or whether we can regard Hertz as one of the forerunners of relativity. We do know, however, that Einstein and other prominent scientists took Hertz' extension of Maxwell's theory and his book on mechanics very seriously.

It is not easy to tell why Hertz' work, so highly regarded in his days, is not well-remembered today. We know that, immediately following Hertz' brilliant successes, the subject of electromagnetic waves was almost shelved by most scientists.

It was only after Marconi's work that the subject of electromagnetic waves took off again, reawakening the scientists' interest.

This was similar to what happened after the discovery of X-rays by Roentgen. There was considerable enthusiasm immediately following their discovery, then they were somewhat forgotten until Bragg in Britain and von Laue in Germany developed the use of X-ray diffraction in crystals.

Maybe it was Marconi's spectacular success, closely following Hertz' early death, which caused Hertz' work to gradually lapse into comparative obscurity. We honour him by using his name as a unit of frequency (1 Hertz = 1 cycle/second), but how many know his importance in the history of science and technology, his stature as a scientist, and how dramatic was the effect of his experimental results on his contemporaries?