# Wireless in the Boer War

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**Abstract**

*The Boer War in South Africa (1899-1902) was the first occasion in which wireless communications were used in a military conflict. This article traces the history from the point of view of both the British and the Boer forces, both of which had intentions to use this latest invention on the field of battle. Marconi's apparatus, in its most elementary form, went with the British Army to the front but failed; the Boers' German equipment was captured and never saw service. The British Army soon rejected wireless but the Royal Navy acquired the apparatus and made it work. No doubt circumstances and personalities played their part but by far the major factor in determining success and failure was the natural electromagnetic environment.*

## 1 INTRODUCTION

The Boer War was declared on 11 October 1899, just three years after Marconi arrived in England from Italy with his elementary wireless signalling apparatus. While described by some as the last of the gentlemen's wars, the Boer War is probably more accurately the war that linked two centuries in time, tactics and technology; it was certainly the first military conflict in which wireless communications were used. The combatants were the commandos of the Boer republics of the Transvaal and the Orange Free State, bolstered by volunteers from Europe, Russia and even the United States, and the British Army supported by contingents from Canada, Australia and New Zealand. The Boers, fiercely independent and determined to remain so in the face of advancing British imperialism across southern Africa, were finally driven to declare war on the British garrison troops over issues of citizenship for the *Uitlanders*, foreigners mainly from England who had been attracted in their thousands following the discovery of gold near Johannesburg in 1886.

At the outset, some 48,000 Boers were ranged against the 27,000 British soldiers then in South Africa. The ferocity and sheer effrontery of the Boer attacks stunned an ill-prepared British force. In Natal, the Army lost a General within a week of the opening salvo and what may have appeared at first to be just an uprising by undisciplined farmers, untutored in the arts of war, immediately took on the trappings of a major confrontation. The Boers, equipped with Mauser rifles imported from Germany for just such an eventuality, were superb marksmen and the smokeless cartridges fired from the saddle or the trench never betrayed their presence. Within a month of that first shot being fired, an expeditionary force of 47,000 men, the largest to leave British shores for nearly a century, was on its way to fight a war in a vast and rugged land [1].

## 2 WIRELESS INTEREST IN THE SERVICES

The British military were amongst the most interested observers at the first demonstrations of Marconi's equipment on Salisbury Plain late in 1896. Representing the Royal Navy was one Captain (later Admiral Sir Henry) Jackson, a pioneer himself in the science of communicating without wires and one of Marconi's most avid supporters. Amongst the Army's observers was Captain J N C Kennedy RE, (figure 1), soon to play a most active part in assisting Marconi with further experiments and then in setting up the first wireless sets to be deployed on the battlefield just three years later [2].


*Fig 1. Capt J N C Kennedy RE*
*Museum of Army Communications, Blandford*

During those tests, and in subsequent experiments over land around Bournemouth and across the sea between there and Alum Bay on the Isle of Wight (a distance of about 23 km), Marconi achieved reliable communications using vertical wire antennas up to 37 m long and connected to earth at one end.

This monopole, as we would term it today, soon became known as the "Marconi aerial". The transmitter (figure 2a) consisted of an induction coil capable of producing 250 mm discharges between the spheres of a spark gap when operated by a Morse key in series with a 14 V battery of Obach cells delivering 6 to 9 A. This transmitter relied entirely on the natural resonance of its antenna for any degree of tuning and, with a similar configuration at the receiver, was referred to at the time as "plain aerial working" [3]. The receiver (figure 2b) made use of Marconi's own version of the coherer – a form of shock-excited switch – connected between the antenna and earth as the detector of the electromagnetic waves. After responding to an electrical impulse, the coherer was restored to its non-conducting state by a 'tapper', which operated within a feedback circuit. The Morse code output from the receiver was then displayed visually on the paper tape of a mechanically-driven inking printer.

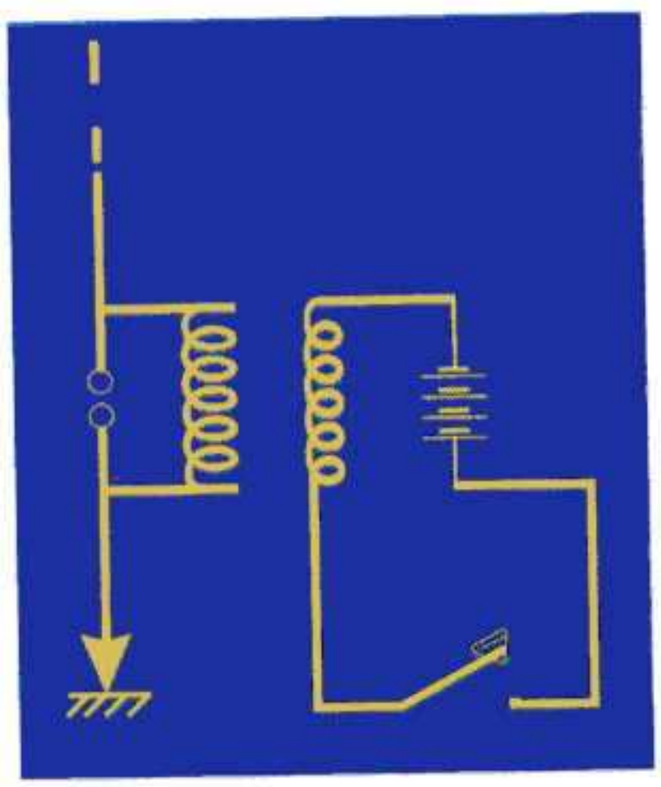

*Fig 2a. The Marconi transmitter*

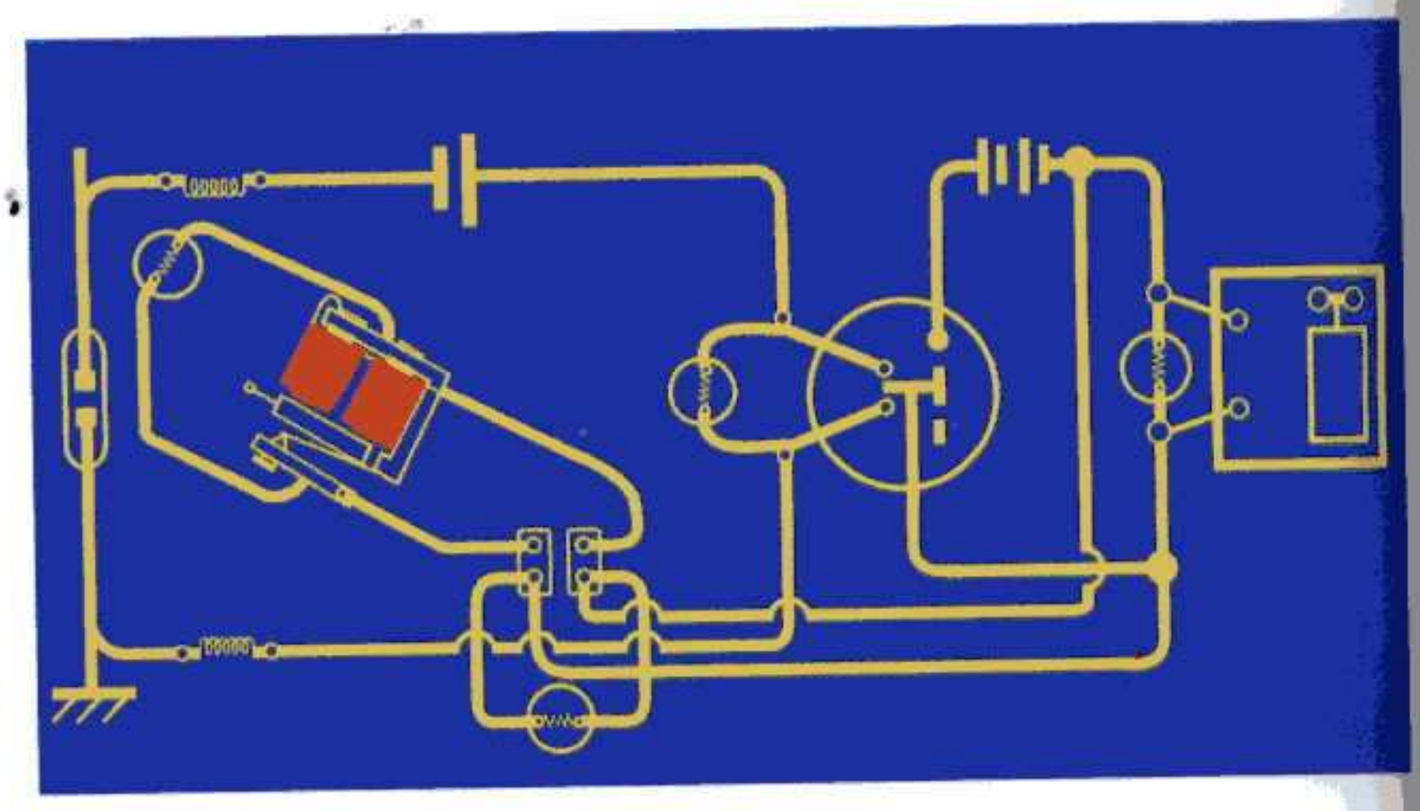

*Fig 2b. The Marconi receiver*

It was the outcome of the Royal Navy's annual manoeuvres in the summer of 1899 that was directly instrumental in the War Office's decision to send Marconi's wireless apparatus to South Africa with the British forces when the war broke out just a few months later. During those manoeuvres, three ships, HMS *Alexandra*, *Europa* and *Juno*, were fitted with Marconi's wireless equipment while Marconi himself sailed aboard *Juno,* which was under the command of Captain Jackson RN [4]. The exercise took the form of a naval encounter between two squadrons, only one of which was equipped with wireless and thus able to communicate well beyond visual range. Marconi's apparatus performed admirably under typically testing naval conditions and a maximum communication range of 136 km was reported. The shipboard antenna, again the only frequency-determining element in the system, was attached to the main topmast and consisted of about 50 m of wire running to the lower after-bridge where the apparatus was housed. Wireless signals, exchanged both by day and night, not only greatly assisted the tactics employed by Captain Jackson's squadron but also proved the efficacy of Marconi's 'jigger', a transformer between the antenna and the transmitter and receiver. Its use brought about a marked increase in sensitivity, and hence in range, and established the principle of impedance matching – itself a major technical advance. However, the lack of any significant tuning or selectivity, except for that provided by the specific length of the antenna, meant that only one transmitter could operate at a time if overwhelming interference were to be avoided. It would be another year before Marconi adopted Oliver Lodge's principle of 'syntony' (what we now call resonance) to markedly improve the sharpness of the tuning of his receiver [5]. Only then would it be possible to select the wanted transmission from the cacophony of noise generated by the impulsive sparks from many transmitters, all operating at the same time.

In view of what was soon to follow on the South African veldt, the key part played by the vertical wire antenna in the communications process was crucial. It was one of Marconi's fellow countryman, a Professor Ascoli, who determined its optimum length when he showed that "the length of the wave radiated (was) four times the length of the vertical conductor".

This result and the recognition by J A Fleming, following Marconi's lecture to the Institution of Electrical Engineers in 1899, of the importance of the quality of the earth connection were to be crucial factors that helped to explain the poor performance of the wireless equipment deployed near Kimberley just a few months later.

## 3 PREPARATIONS FOR WAR

Britain certainly underestimated both the will of the Boers to fight and their resourcefulness to do so once hostilities commenced. By 14 October 1899, just three days after the first probing shots were exchanged, the towns of Kimberley and Mafeking, plus their encamped British troops, were under siege. Two weeks later, Ladysmith suffered the same fate. On 14 October, too, three divisions of infantry plus supporting cavalry set sail from Southampton for the Cape. With them went six engineers from the Marconi Company (Messrs Bullocke, Dowsett, Elliott, Franklin, Lockyer and Taylor), some RE sappers to supply the necessary manual labour (figure 3), as well as five so-called portable wireless stations made up of the Marconi apparatus of the time. In command of the RE detachment was Captain Kennedy, by now an acknowledged expert in its use.

*Fig 3. Marconi engineers and Royal Engineers sappers in South Africa, 1899 (GEC-Marconi Archives)*

It was originally intended that the wireless sets would be used for ship-to-shore communications by deploying them at the ports of disembarkation. By so doing, it was hoped to coordinate the process of landing masses of men, stores, horses and the other impedimenta of war. However, soon after their arrival in Capetown in December 1899, Bullocke, at Captain Kennedy's request, "gave a show" of the equipment's capabilities for the General, his staff officers and military attaches at the Capetown Castle. It went off successfully even though the distance signalled was but a token "few hundred yards" [6]. No doubt impressed by this achievement and reinforced by Kennedy's firsthand account of the results on Salisbury Plain, the planning staff decided to deploy the five wireless sets and their operators at the front, and Marconi's engineers indicated their willingness to accompany the equipment and to prepare it for action.

Neither the British commanders in South Africa about to set out for the hinterland nor their government at home had appreciated quite how thoroughly President Kruger had been preparing for war. Ever since the abortive Jameson Raid of 1896 that had tried to wrest control of the Transvaal from the Boers, he had been stockpiling considerable quantities of weapons and ammunition. By July 1899, after the breakdown of talks with the British High Commissioner Sir Alfred Milner, war seemed inevitable and Kruger was prepared. In addition to his commandos, his *Staats Artillerie* was also well equipped and well trained thanks, particularly, to the ready support given to the Boer republics by Germany. Signalling, too, was afforded a high priority and the Republics' telegraphic communications networks had been rapidly expanded in recent years. As early as 1897, the State Telegraph Department in the Transvaal, and that supporting the railway network, began to upgrade their lines and to train telegraph operators by the score [7]. The network eventually became so extensive that by the outbreak of war all the Boer laagers around Ladysmith were in contact with each other and with their headquarters in Pretoria, and heliographs were in general use [8]. But wires and cables are vulnerable both to attack and to 'tapping', an art in which the Boers were well-versed, and the 'helio' did not work at night so some other means was required to link the various forts that ringed Pretoria.

Kruger's General Manager of Telegraphs, C K van Trotsenburg, was an able engineer who had followed developments in the world of wireless communications with much interest and was therefore in a position to offer a solution. He had already investigated the supply of suitable wireless telegraphy equipment for the forts and had received quotations for the necessary apparatus from Messrs Siemens and Halske in Berlin, the *Societe Industrielle des Telephones* in Paris and, most intriguingly, from the Wireless Telegraph and Signal Company Ltd in London – Marconi's very own company[1]. After visiting Europe in July to inspect each company's equipment, Meneer van Trotsenburg decided in favour of the German apparatus (figure 4) and an order for six sets of *vonkeltelegraafinstrumenten* (spark telegraph instruments) was placed with Siemens and Halske on 24 August 1899 [9]. This was in addition to the heliographs, signal flags, compasses and field glasses that the company had already supplied to the Boers [10]. The wireless equipment was duly broken up and loaded aboard five vessels, presumably in the interests of security, which sailed from Hamburg for South Africa early in October 1899.

*Fig 4. A reconstruction of the Siemens and Halske receiver supplied to the Boers (Siemens AG)*

[1] In an address at The Royal Institution on 2 February 1900, after it had been mentioned that the Boers had attempted to obtain wireless apparatus, Signor Marconi stated: "I need hardly add that as no apparatus has been supplied by us to any one (sic), the Boers cannot possibly have obtained any of our instruments." What he neglected to say was that his company had been quite willing to do business with Kruger!

It transpired that Kruger's forces were never to see the Siemens wireless apparatus. By the time the six sets, their masts, accumulators and other paraphernalia arrived in Capetown, war had already broken out and the equipment was impounded by Customs. Word of this soon reached Captain Kennedy and he duly inspected the booty, cannibalizing some of its elements for use with his own apparatus soon to be deployed [11].

## 4 WIRELESS WITH THE ARMY

In the first week of December 1899, Marconi's engineers, Kennedy's sappers and the five "portable wireless installations", left Capetown for De Aar, an important railway junction and dispersal point for British troops moving north to the besieged towns of Kimberley and Mafeking (figure 5). Certain shortcomings in the provision of equipment were already apparent. Most important was the lack of suitable masts or poles with which to support the wire antennas. Since the antennas would turn out to be the key elements in the system, this was serious. The poles supplied with the Marconi equipment were too bulky for use in the field and were discarded, while those purloined from the Custom's shed in Capetown were equally unsuitable. It was therefore decided to make use of local 9 m bamboo poles that could be lashed together to reach an adequate height. In addition, an order was placed, in all haste, for a number of balloons and kites from the Royal Engineers Balloon School at Aldershot. These would then augment the few that Kennedy had been able to borrow and would ensure that he and his men could get the wires aloft.

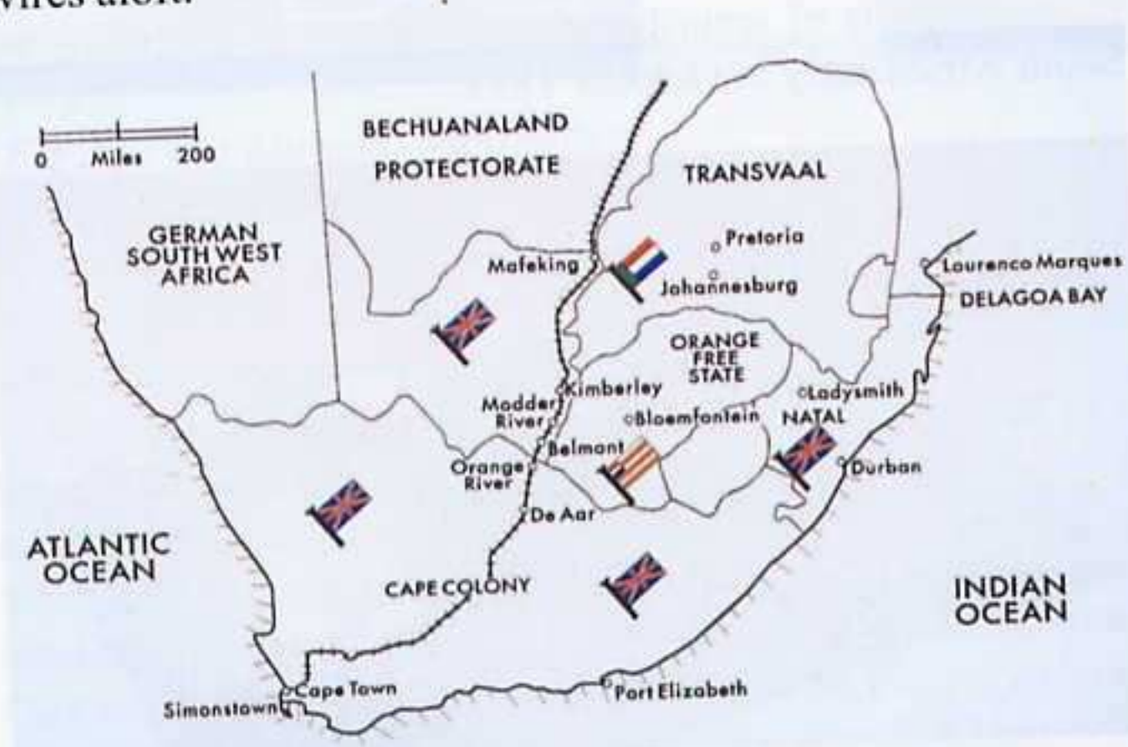


*Fig 5. South Africa at the time of the Boer War*

From De Aar, three of the sets, plus their civilian operators, were transferred to the military encampments at Orange River, Belmont and Modder River with the intention of establishing wireless communications between them. In addition, a wireless wireless communications between them. In addition, a wireless station was also set up at Enslin "about 27 kms from Modder" (figure 6) where, according to Bullocke, Lord Methuen commanding the 1st Infantry Division feared "a surprise" from the Boers.

While in transit from Capetown, the wireless contingent witnessed their first severe South African thunderstorm and reported that the accompanying lightning was "the most vivid any of us had ever seen". It was confirmed to Bullocke by those in the know that such pyrotechnics were almost a daily occurrence in that part of the world at that time of the year. This duly prompted him to remark in his letter of 11 December to the Company back home in England that it would be a "delightful time for Xs", the accompanying atmospherics that so disrupted wireless communications.

On setting up the equipment a week later, Bullocke reported that attempts to communicate between De Aar and Orange River, some 112 km apart, were unsuccessful. He stated that he had used "a curly aerial about 18 m in height and [a] good earth", yet in spite of that could not explain the lack of success. Problems abounded. Kennedy, at De Aar, resorted to using kites but there was insufficient wind to allow them to be flown that day. When there was, he was able to elevate a wire to a height of 152 m but had no success either, because Elliott, at Orange River, "had broken his pole" [12]. But they persisted doggedly and at the end of the month had some success when contact was made between Orange River and Modder River, a distance of 80 km, but only by using an intermediate or relay station at Belmont, and such achievements were few.

Attempts to make the Marconi equipment function reliably in the field continued for a further six weeks but were thwarted for at least half the time because most sets were unusable: if cyclonic dust storms had not splintered the bamboo masts, or lightning discharges overwhelmed the coherers, the wind was either too weak to fly the kites or so fierce as to tear away the balloons. Not surprisingly, on 12 February 1900, the Director of Army Telegraphs gave orders for the three sets along the Kimberley line to be dismantled. This fate soon followed the two others that had been dispatched a month before, along with Messrs Bullocke, Taylor and Captain Kennedy, to join General Buller's forces attempting to relieve the besieged town of Ladysmith [13]. Since neither Marconi's employees nor Captain Kennedy could offer what he considered a reasonable explanation for this state of affairs, the Adjutant General, Sir Evelyn Wood, duly had the wireless equipment sent to the Royal Navy in Simonstown where he believed they might have some use for it.

## 5 SUCCESS IN THE NAVY

The pre-war naval manoeuvres of 1899 were very significant in the history of wireless in general and military wireless in particular. The lack of any success by the Army with this hastily-assembled Marconi apparatus, for whatever reason, did

*Fig 6. Enslin camp, 1899*

not deter the Royal Navy from installing the discarded wireless sets on board five cruisers operating a blockade in Delagoa Bay, Portuguese East Africa. The admirals remembered only too well how effective wireless had been during those manoeuvres just the year before. The particular task now facing the Royal Navy was to stop and search any merchantman heading for the port of Lourenco Marques (now Maputo) that was suspected of carrying military contraband destined for the Boers. Any measure that would assist in this was welcome and effective ship-to-ship communications certainly fell into that category. And so the wireless apparatus was transferred to the Delagoa Bay Squadron and on 17 March 1900 a set was fitted in the cruiser HMS *Thetis* (figure 7), which thus became the first naval vessel to carry wireless equipment in an active theatre of war. Soon her sister ships HMS *Forte*, *Magicienne*, *Dwarf* and *Racoon* would be similarly equipped and the blockade operation was pursued in earnest [14].

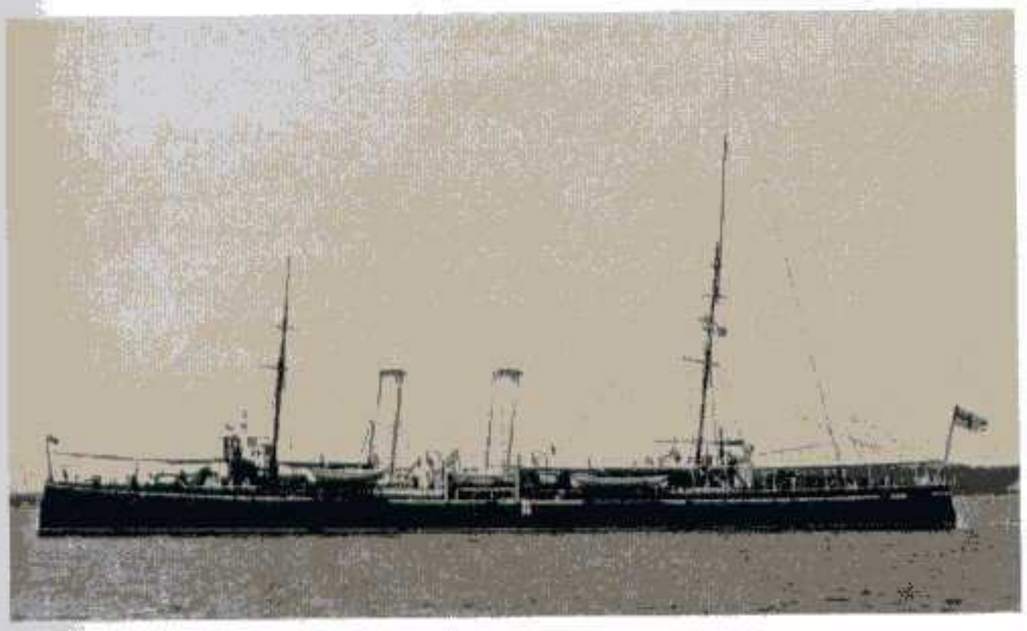

*Fig 7. HMS* Thetis *showing the extended mast carrying the antenna*

In great contrast to the recent dismal results on land, wireless communication at sea proved to be an unqualified success. Its use turned out to be invaluable to the Navy for, not only could the cruisers cover a wider search area while still remaining in contact, but concerted action was possible while both out of sight of each other and of their quarry. In addition, speedy communication was possible between the ships at sea and the Commander-in-Chief at Simonstown, about 1600 km away, by using the *Magicienne*, lying at anchor in the bay, to relay messages via a landline link to the shore and thence via the telegraph network to the Cape.

To use the wireless equipment effectively required that the masts of the ships be extended to accommodate the long wire antenna. HMS *Thetis*, under the command of Captain Stokes-Rees, duly raised hers to a height of 44 m above the water line for this purpose. Tests conducted on 13 April 1900 yielded a range of 85 km, which greatly increased the flexibility of the blockage operations. Subsequently, she was fitted with a horizontal, twin-wire antenna, which proved to be so successful that thereafter this became the standard installation on naval vessels.

The wireless equipment remained in service with the Royal Navy until November 1900 when it eventually went into storage owing, almost certainly, to the change in the nature of the war on land. The Boers, though in retreat, were by no means defeated. For the next 18 months they fought a bitter guerrilla campaign against a British Army that now numbered almost half-a-million men under the command of General Lord Kitchener. Wireless played no further part. It had served its immediate purpose and, though a failure on land, it had ushered in a new era for the Navy. Its success in Delagoa Bay, coupled with the experience of the naval manoeuvres in 1899, was undoubtedly behind the decision to equip 42 ships and eight shore stations around Britain with wireless by the end of 1900 [15].

## 6 A MODERN PERSPECTIVE

Much has been written about the failure of the wireless equipment when tried by the Army but rather less has appeared about the success achieved when used by the Royal Navy. It should be appreciated that each service had use of the equipment for roughly the same length of time and in both cases it was set up and operated by the same six engineers from the Marconi company, and yet its performance was markedly different in the two theatres of operations. One has to ask why this should have been so.

When wireless proved so disappointing on the South African veldt after the favourable reports that followed both the Salisbury Plain demonstrations in 1896 and the naval manoeuvres of 1899, the immediate reaction of Signor Marconi was to blame the military authorities for "their lack of proper preparation" by not providing the correct poles to support the antennas. Some observers closer to the scene also suggested it was due to "the iron in the hills", while Marconi's own engineers, though having some sympathy with their employer's view, also believed that the locality of the north-western Cape Colony, both geological and meteorological, may well have had somewhat more to do with it. The subsequent success achieved by the Navy using the same equipment, but in a vastly different environment, leads one to conclude that antennas, geology, meteorology and the season of the year were, indeed, all to blame.

The 'plain aerial working' used by the Marconi equipment meant that the particular frequency on which a transmitter radiated maximum energy was determined solely by the length of that vertical wire, whether attached to mast, kite or balloon, *and* by the quality of the electrical connection to the earth below. Essentially, when the wire was a quarter wavelength and the earth connection was sound, the system would have been at its most efficient but only at that particular frequency. The implication of this for the British Army when it tried to use the equipment with makeshift antennas on what were described as the "dry, sandy plains of the Northern Karroo", was that no two wireless installations were ever likely to have been operating on exactly the same frequency because the antenna lengths were so variable and the earth connections so poor. This fundamental problem was to some extent offset by the lack of selectivity elsewhere within the primitive systems and by the essentially broadband nature of the spark transmitters. But the poor earth connections would also have introduced loss, which in turn would have reduced significantly the amount of power both radiated by the antenna and propagated by the ground wave that was almost certainly the mode of signal propagation at the sort of frequencies involved.

Since the Marconi receiver consisted of little more than a coherer, its performance, and hence the range over which communications would have been possible, were entirely dependent on the power radiated by the transmitting antenna, and on the electrical conductivity of the ground beneath both antennas and between the wireless stations themselves. Bullocke and his men appreciated this to some extent since it was reported that "sheets of tin" (probably galvanized iron) were buried beneath the antenna masts to improve matters, but all was to no avail because other natural phenomena also conspired against them.

It was shown somewhat later by Vice [16] that the ground conductivity south-west of Kimberley was typically between 6.5 and 10 mS $m^{-1}$ at a frequency of 500 kHz (figure 8). At a guess, Marconi's equipment might have operated anywhere from 500 kHz to about 4 MHz, depending upon the length of the antenna actually deployed, thus some variation in conductivity would be expected over that range. Whatever it was, these values should be compared with the 14 mS $m^{-1}$ at 1 MHz that is typical of Salisbury Plain, the site of so many of Marconi's early experiments [17]. Not only would the antennas have been more efficient in England but the ground wave would have suffered less attenuation as it propagated along the surface of the more highly conducting earth. By contrast, when used by the Royal Navy, the considerably higher conductivity of the sea water (4000 mS $m^{-1}$) would have enhanced significantly both the performance of the antennas and the propagation over the surface of the sea. Thus, whether in the Atlantic Ocean in 1899 or in the Indian Ocean less than a year later, one reason for the Royal Navy's consistent success with wireless is readily apparent.

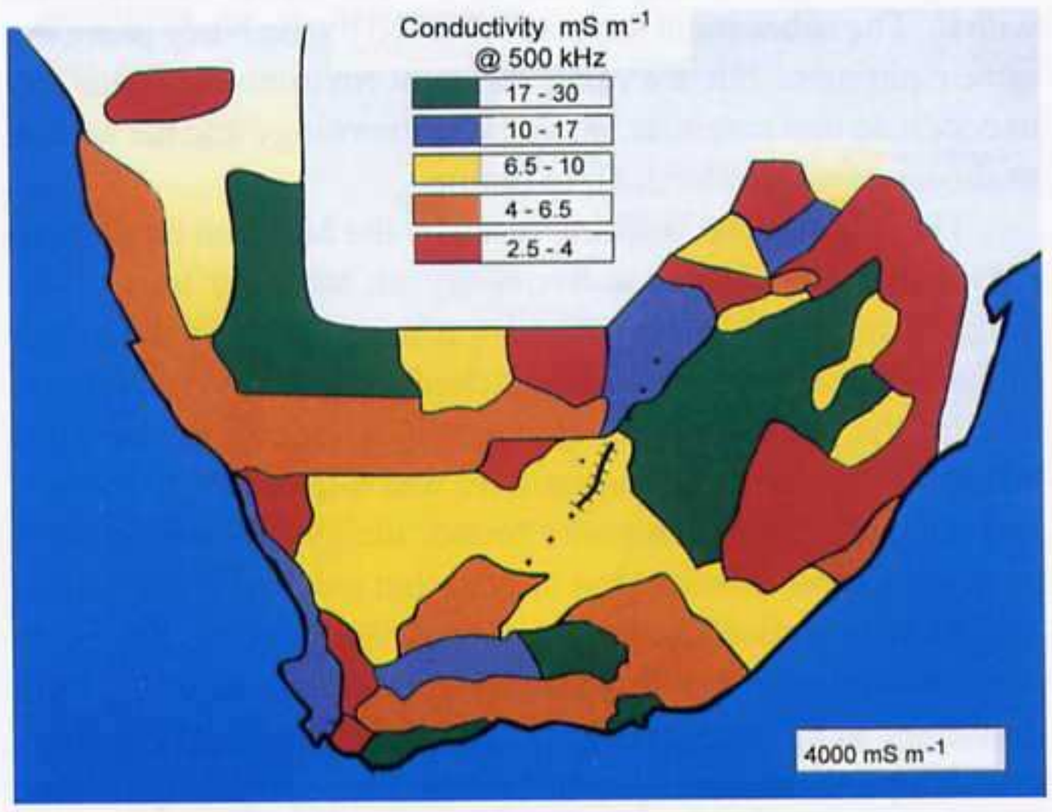


*Fig 8. Map of ground conductivity in South Africa after Vice [16]*

There is an additional important factor that must also be considered and that too was frequently commented upon by Marconi's engineers at the front: the intensity of the lightning on the South African veldt and the paralysing effect it had on the coherers in the receivers. South Africa is one of those regions of the world in which severe lightning is but a fact of life, certainly for part of the year during the summer months [18]. Measured as the number of lightning flashes per square kilometre per year, the region south-west of Kimberley has typically three to five such events that occur predominantly between November and April, the height of the southern hemisphere summer (figure9). This was precisely when the British Army was hoping for useful service from its secret weapon, Marconi's wireless apparatus. By contrast, once again, the level of lightning activity for the whole of the British Isles never exceeds one flash per square kilometre per year [19], and none was reported during Marconi's demonstrations on Salisbury Plain nor any during the manoeuvres at sea. When the Royal Navy equipped its Delagoa Bay Squadron with these discarded wireless sets during March, and then used them throughout the winter months, such heavenly pyrotechnics were essentially non-existent. Thus, not only did the ships benefit from better antennas and propagation conditions, but the signal-to-noise ratio, in modern parlance, would have been markedly better too, given the absence of lightning and its attendant 'Xs' that had so plagued the Army on the ground just a few months before.

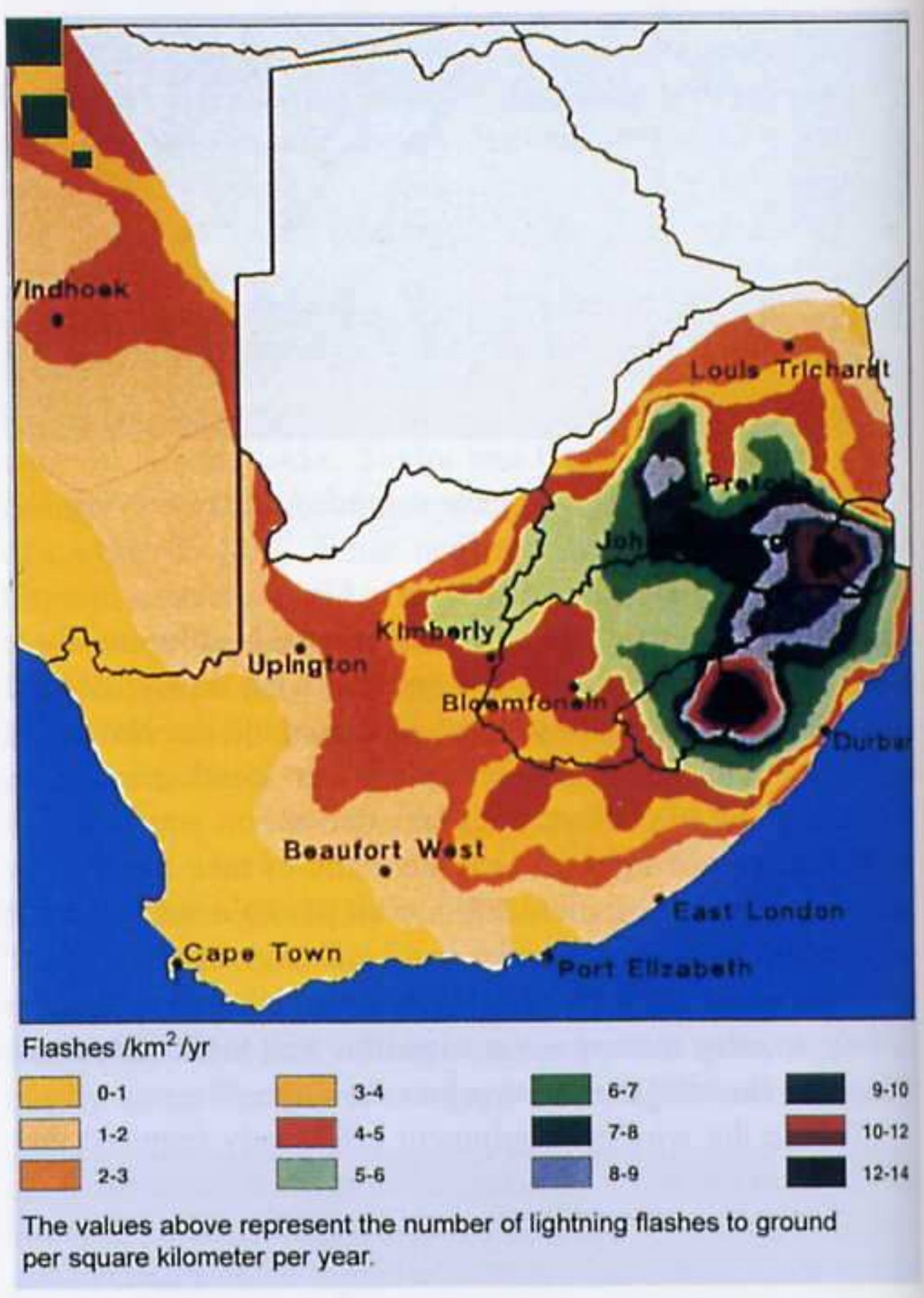


*Fig 9. Map of lightning ground flash distribution in South Africa (Eskom [18])*

## 7 CONCLUSION

The history of wireless is replete with stories of its origins but probably none is more intriguing than that describing its first use in a military conflict. That it actually took place a century ago during the Boer War is a fact worth recording in its own right but, to record only the disappointing performance achieved by Marconi's apparatus when rushed into service in

a role for which it was never intended does not tell the full story. It can so easily be presented as but an ill-judged attempt to use a revolutionary new technology before it was ready, but that would be to ignore totally its performance at sea. For reasons not understood at the time, wireless failed to assist the Army but it more than proved itself on board Her Majesty's ships. We now know that there were many factors involved, not least of which were the geophysical conditions that prevailed in southern Africa. They, probably more than anything else, determined the outcome of this first use of wireless in warfare.

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**References**

1 Pakenham T. *The Boer War*. Macdonald and Co., London (1979).

2 Marconi G. *Wireless Telegraphy*. J.IEE 28 273 (1899).

3 Dowsett H M. *Wireless Telegraphy and Broadcasting*. Vol.1. Gresham Publishing Co., London (1923).

4 Marconi G. *Wireless Telegraphy*. Proc of the Royal Institution **16** 247 (1899-1901).

5 Aitken H G J. *Syntony and Spark - the origins of Radio*. Princeton University Press (1985).

6 Bullocke G L. *Correspondence with the Marconi Company 11.12.1899-2.5.1990*. The Marconi Company, London.

7 Breytenbach J H. *Geskiedenis van die Tweede Vryheidsoorlog*. Government Printer, Pretoria (1969).

8 Amery LS (ed.) *The Times History of the War in South Africa 1899-1902*. **2** 82; **6** 361 (1900-1909).

9 Baker D C. *Wireless telegraphy during the Anglo-Boer War of 1899-1902*. Military History Journal **11** (2), 37 South African Military History Society (1998).

10 Jacobs F J, Bouch R J, du Preez S and Cornwell R. *South African Corps of Signals*. SADF Documentation Service, Pretoria (1975).

11 Day E D. *Through to 1970*. Royal Signals Institution, London (1970).

12 Kennedy J N C. *Personal Boer War Diary*. The Royal Signals Museum, Blandford. (1899).

13 Baker W J. *A History of the Marconi Company*. Methuen and Co., London. (1970).

14 Hezlet A. *The Electron and Sea Power*. Peter Davies, London (1975).

15 Pocock R F and Garratt G R M. *The Origins of Maritime Radio*. HMSO, London (1972).

16 Vice R W. A survey of ground wave propagation conditions in South Africa. Trans South African Institute of Electrical Engineers **45** 139 (1954).

17 CCIR. *World Atlas of Ground Conductivities*. Report 717-2. International Telecommunications Union, Geneva (1986).

18 Redelinghuys M. *Eskom South Africa: personal communication* (1995).

19 Golde R H. Lightning Vol.1. Academic Press, London (1977).

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